103

FUTURE USES OF SATELLITE TECHNOLOGY IN AVIATION

(103–33)

Y 4.P 96/11:103-33

Future Uses of Satellite Technology...

HEARING

BEFORE THE

SUBCOMMITTEE ON AVIATION

OF THE

COMMITTEE ON
PUBLIC WORKS
AND TRANSPORTATION
HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRD CONGRESS

FIRST SESSION

JULY 28, 1993

Printed for the use of the
Committee on Public Works and Transportation

DEC 17 1993

73–500

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON : 1993

For sale by the U.S. Government Printing Office
Superintendent of Documents, Congressional Sales Office, Washington, DC 20402
ISBN 0-16-041774-0

73-500 O - 93 - 1

103

FUTURE USES OF SATELLITE TECHNOLOGY IN AVIATION

(103–33)

4. P 96/11: 103-33

ure Uses of Satellite Technology...

HEARING

BEFORE THE

SUBCOMMITTEE ON AVIATION

OF THE

COMMITTEE ON
PUBLIC WORKS
AND TRANSPORTATION
HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRD CONGRESS

FIRST SESSION

JULY 28, 1993

Printed for the use of the
Committee on Public Works and Transportation

DEC 17 1993

U.S. GOVERNMENT PRINTING OFFICE
73–500 WASHINGTON : 1993

For sale by the U.S. Government Printing Office
Superintendent of Documents, Congressional Sales Office, Washington, DC 20402
ISBN 0-16-041774-0

COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION

NORMAN Y. MINETA, California, *Chair*

JAMES L. OBERSTAR, Minnesota
NICK JOE RAHALL II, West Virginia
DOUGLAS APPLEGATE, Ohio
RON de LUGO, Virgin Islands
ROBERT A. BORSKI, Pennsylvania
TIM VALENTINE, North Carolina
WILLIAM O. LIPINSKI, Illinois
ROBERT E. WISE, Jr., West Virginia
JAMES A. TRAFICANT, Jr., Ohio
PETER A. DeFAZIO, Oregon
JIMMY HAYES, Louisiana
BOB CLEMENT, Tennessee
JERRY F. COSTELLO, Illinois
MIKE PARKER, Mississippi
GREG LAUGHLIN, Texas
PETE GEREN, Texas
GEORGE E. SANGMEISTER, Illinois
GLENN POSHARD, Illinois
DICK SWETT, New Hampshire
BUD CRAMER, Alabama
BARBARA-ROSE COLLINS, Michigan
ELEANOR HOLMES NORTON, District of Columbia
LUCIEN E. BLACKWELL, Pennsylvania
JERROLD NADLER, New York
SAM COPPERSMITH, Arizona
LESLIE L. BYRNE, Virginia
MARIA CANTWELL, Washington
PAT (PATSY ANN) DANNER, Missouri
KAREN SHEPHERD, Utah
ROBERT MENENDEZ, New Jersey
JAMES E. CLYBURN, South Carolina
CORRINE BROWN, Florida
NATHAN DEAL, Georgia
JAMES A. BARCIA, Michigan
DAN HAMBURG, California
BOB FILNER, California
WALTER R. TUCKER, California
EDDIE BERNICE JOHNSON, Texas
PETER W. BARCA, Wisconsin

BUD SHUSTER, Pennsylvania
WILLIAM F. CLINGER, Jr., Pennsylvania
THOMAS E. PETRI, Wisconsin
SHERWOOD BOEHLERT, New York
JAMES M. INHOFE, Oklahoma
BILL EMERSON, Missouri
JOHN J. DUNCAN, Jr., Tennessee
SUSAN MOLINARI, New York
WILLIAM H. ZELIFF, Jr., New Hampshire
THOMAS W. EWING, Illinois
WAYNE T. GILCHREST, Maryland
JENNIFER B. DUNN, Washington
TIM HUTCHINSON, Arkansas
WILLIAM P. BAKER, California
MICHAEL A. (MAC) COLLINS, Georgia
JAY KIM, California
DAVID A. LEVY, New York
STEPHEN HORN, California
BOB FRANKS, New Jersey
PETER I. BLUTE, Massachusetts
HOWARD P. (BUCK) McKEON, California
JOHN L. MICA, Florida
PETER HOEKSTRA, Michigan
JACK QUINN, New York

SUBCOMMITTEE ON AVIATION

JAMES L. OBERSTAR, Minnesota, *Chair*

RON de LUGO, Virgin Islands,
Vice Chair
WILLIAM O. LIPINSKI, Illinois
PETE GEREN, Texas
GEORGE E. SANGMEISTER, Illinois
BARBARA-ROSE COLLINS, Michigan
SAM COPPERSMITH, Arizona
ROBERT A. BORSKI, Pennsylvania
TIM VALENTINE, North Carolina
PETER A. DeFAZIO, Oregon
JIMMY HAYES, Louisiana
BOB CLEMENT, Tennessee
JERRY COSTELLO, Illinois
MIKE PARKER, Mississippi
GREG LAUGHLIN, Texas
DICK SWETT, New Hampshire
BUD CRAMER, Alabama
LUCIEN E. BLACKWELL, Pennsylvania
MARIA CANTWELL, Washington
PAT (PATSY ANN) DANNER, Missouri
KAREN SHEPHERD, Utah
CORRINE BROWN, Florida
NORMAN Y. MINETA, California
(Ex Officio)

WILLIAM F. CLINGER, Jr., Pennsylvania
SHERWOOD BOEHLERT, New York
JAMES M. INHOFE, Oklahoma
JOHN J. DUNCAN, Jr., Tennessee
THOMAS W. EWING, Illinois
WAYNE T. GILCHREST, Maryland
JENNIFER B. DUNN, Washington
MICHAEL A. (MAC) COLLINS, Georgia
JAY KIM, California
DAVID A. LEVY, New York
STEPHEN HORN, California
HOWARD P. (BUCK) McKEON, California
JOHN L. MICA, Florida
BUD SHUSTER, Pennsylvania
(Ex Officio)

CONTENTS

Page
Summary of subject matter VII

TESTIMONY

Beukers, John M., Beukers Technologies 43
Broderick, Anthony J., Associate Administrator for Regulation and Certification, Federal Aviation Administration 9
Brown, Steven J., senior vice president, government and technical affairs, Aircraft Owners and Pilots Association 43
Eschenbach, Ralph F., vice president, navigation division, Trimble Navigation Limited 81
Faville, Will, director, safety and technology, National Air Traffic Controllers Association, MEBA/AFL–CIO 71
Ferguson, Robert R., III, president and chief executive officer, Continental Airlines, Inc 36
Fleming, J. Roger, senior vice president, operations and services, Air Transport Association of America, Inc 43
Haapala, Capt. David R., director, flight operations development, Northwest Airlines 43
Johannssen, Howard E., chairman, Professional Airways Systems Specialists [PASS] 71
McCleary, Chris, vice president, sales and marketing, American Mobile Satellite Corp 81
Mineck, David W., director, advance systems, Collins Commercial Avionics, Rockwell International, on behalf of the General Aviation Manufacturers Association 81
O'Brien, John, director, engineering and safety, Air Line Pilots Association 43
Peña, Hon. Federico, Secretary, U.S. Department of Transportation 6
Poritzky, Siegbert B., senior vice president, Airports Council International North America 43
Pozesky, Martin (Marty), FAA Associate Administrator, System Engineering and Development, Federal Aviation Administration 9
Watrous, David S., president, RTCA, Inc 43

PREPARED STATEMENTS SUBMITTED BY MEMBERS OF CONGRESS

Blackwell, Hon. Lucien E., of Pennsylvania 5
Collins, Hon. Barbara-Rose, of Michigan 5
Costello, Hon. Jerry F., of Illinois 4

PREPARED STATEMENTS SUBMITTED BY WITNESSES

Beukers, John M 92
Brown, Steven J 113
Eschenbach, Ralph F 119
Faville, Will 152
Ferguson, Robert R., III 157
Fleming, J. Roger 169
Haapala, Capt. David R 176
Johannssen, Howard E 184
McCleary, Chris 190
Mineck, David W 193
O'Brien, John 202
Peña, Hon. Federico 207

	Page
Poritzky, Siegbert B	211
Pozesky, Martin	229
Watrous, David S	242

SUBMISSION FOR THE RECORD

Clinger, Hon. William F., Jr., a Representative in Congress from Pennsylvania, responses to post-hearing questions submitted to the FAA	25

MEMORANDUM

To: Members of the Subcommittee on Aviation
From: Committee's Aviation Staff
Date: July 26, 1993
Re: Summary of subject matter for Aviation Subcommittee hearing on Future Uses of Satellite Technology in Aviation, July 28, 1993.

The Subcommittee will receive testimony on the future uses of satellite technology in the aviation system, the potential benefits of this technology, the adequacy and timing of government and industry programs for furthering the development of satellite technology, and the policy choices facing government and industry as satellites are brought into the aviation system.

I. BACKGROUND

Any changes to the aviation system brought about by satellite technology will certainly come incrementally, but a consensus is developing in the world's aviation community that the changes that could come about could be relatively swift and very far-reaching. Some observers look upon satellite technology as a "shift in the paradigm" upon which the aviation system is built; that is, it would be a change similar in magnitude to instituting radio, radar, the civil jet engine, or automatic data processing to the aviation system.

Also generating interest and excitement in the potential of satellite technology is the fact that the technology that aviation would use is largely developed, in place, understood, and already in use for primarily non-aviation applications. This is not technology still on the drawing board or a gleam in an engineer's eye.

Last month, the Space Shuttle delivered the final Global Positioning System (GPS) satellite into orbit for the Department of Defense providing a full constellation of 24 satellites. GPS has been an ongoing program of the Department of Defense to provide precise navigation for ships, aircraft, trucks, and soldiers. GPS, even before it was fully deployed, was used extensively and successfully in the war with Iraq in 1991.

GPS is owned and operated by the Department of Defense, but the signals can be received and used by anyone with a GPS receiver, which is typically the size of a large hand held calculator.

GPS receivers can be bought by ordinary individuals for just a few hundred dollars out of catalogues and consumer electronics stores. Use of GPS by trucking companies, rail, ambulance services, and commercial and recreational boating is becoming ubiquitous. New applications for GPS are being introduced rapidly.

GPS relies on a constellation of satellites that transmit signals enabling a civil receiver on the ground or in the air to calculate the exact distance, to an accuracy of approximately 100 meters in the horizontal plane and 300 meters in the vertical plane, that the receiver is from the satellite. Positions are calculated by a receiver measuring the time a signal from a group of satellites takes to reach the receiver. The receiver translates the time measurement into a distance from the satellites. Through a triangulation-type calculation these measurements are further translated into latitude, longitude, altitude, and speed of movement.

II. POTENTIAL OF SATELLITES FOR AVIATION

A report issued last September by a Radio Technical Commission on Aeronautics (RTCA) task force found the implementation of a global navigation satellite system would provide benefits and opportunities to aviation into two broad areas:

A significant improvement in the accuracy and timeliness of aircraft position information everywhere in the world; and

A fundamental change in how aircraft operations and associated procedures are managed.

The following specific benefits and opportunities have been identified.

The ability to determine aircraft positions to an initial accuracy of at least 100 meters can now be accomplished routinely anywhere in the world. With further improvements and augmentations, accuracy can likely be improved to a few meters in both the horizontal and vertical planes. Current ground based technology can be inaccurate up to hundreds of meters in some circumstances. Over the oceans, position accuracy is even lower because there is no radar coverage. Today accuracy is measured over the oceans in terms of miles.

The improved accuracy of determining positions by satellites would permit the safe reduction of aircraft separation standards, particularly over the oceans. Because of current inaccuracies, aircraft operating over the oceans are provided a bubble of airspace 50 miles in diameter. Closer spacing would reduce delays and improve efficiency. Aside from using satellites for navigation, satellite communications have been tested as a means to transmit on-board position readings to air traffic controllers. This approach has come to be known as Automatic Dependent Surveillance (ADS) and appears to hold promise particularly over the ocean.

Generally, it is expected that satellite navigation will permit more direct flight paths, thus reducing flight time and fuel consumption. Aircraft today typically operate over flyways between ground based navigation facilities. Flight segments between these facilities typically do not line up in straight lines.

Many parts of the world have little or no ground-based navigation system for aviation. Satellites can provide very accurate navigation in these areas with no need to build costly navigation infrastructure on the ground. As an example, a staffer of the Aviation Subcommittee, on a personal vacation, piloted an aircraft over a very remote area of Bolivia that appeared as white uncharted territory on her aeronautical chart. Using a GPS receiver, she was able to find a particular remote strip in a new National Park hundreds of miles from where she took off.

Satellite based navigation would permit more varied and complex approaches in terminal areas. It is generally assumed that satellite technology can provide non-precision approaches to airports, (meaning it could put the aircraft in close proximity to an airport, but not be able to guide the aircraft all the way to the ground by instruments). With modifications, it is also generally assumed that precision approaches with satellites will also be possible. (Precision approaches are those assisted by instruments in low or no visibility situations). Presently precision approaches are made using instrument landing systems (ILS) which require aircraft to line up at a particular fix several miles from a runway's end. Satellites would create airspace capacity by enabling aircraft to approach the runway from a variety of points and angles to the runway. Microwave landing systems can provide this capability, too, but MLS brings no other benefits to the system. The aviation community has lost enthusiasm for MLS and believes the program should be dramatically scaled back.

Further, satellite-based navigation could obviate the cost of full implementation of the FAA's microwave landing system (MLS) program. FAA presently plans to establish microwave landing systems at over 1,000 runway ends at a cost of over $1 billion. Satellite navigation with precision approach capabilities could result in a similar savings.

Satellite technology could eventually eliminate the need for a large number of ground-based navigation aids. Current en route and terminal navigation systems consist of thousands of individual beacons and transmitters, much of which are quite antiquated technologically. Eliminating this equipment would save millions of dollars a year in maintenance and upgrading expenses.

If satellite navigation technology comes into widespread use, other on board navigation systems could be replaced, saving installation and maintenance costs as well as weight. Training on these different systems could be eliminated as well.

Specialized aviation services, such as off shore oil operations and medieval evacuation services, could benefit with improved and more accurate navigation.

The accuracy of satellite navigation could be used to improve the safety of ground operations and thereby prevent runway incursions and accidents. Control of non-aircraft ground vehicles could also be improved.

Standard separation of parallel runways in instrument conditions would be safely lessened using satellite navigation, thereby enhancing capacity at a number of major airports.

Some observers have theorized a concept of the "autonomous aircraft"; that is an aircraft that operates in the airspace, largely free of any air traffic control. An aircraft with a highly accurate satellite navigation system and advanced collision and avoidance equipment could operate "autonomously," flying when and where it wanted to, except to be metered in or out of an airport. If this were ever to come into being, the cost savings to the government and industry would be in the billions of dollars annually.

III. ISSUES AND PROBLEMS THAT NEED TO BE ADDRESSED

While the use of satellite technology appears to be upon us, there are a number of significant issues and problems that must be worked through and resolved before many of the potential benefits of satellite technology are actually realized. Some of the issues are technical, but these appear to be fairly well understood by the aviation community and resolvable from a technical standpoint. Other issues are more difficult because they involve changing the way large bureaucratic institutions in government and industry do business.

While the GPS system provides a great enhancement to the accuracy of en route positioning and navigation, it is not accurate enough to provide for a precision approach in low visibility conditions. The reason for this shortcoming is that accuracy is a function of the number of satellites involved in the position determination. The present constellation is configured to provide, at most, four "visible" satellites to a GPS receiver at any one time. In order to get the accuracy required for precision approaches, either more satellites will be needed or other measures will be needed to augment the existing of satellites.

One possibility would be to use an existing accuracy refinement already available in the GPS system. GPS satellites actually broadcast two signals, one more accurate than the other. Presently, the Department of Defense (DoD), for reasons of national security, blocks the GPS signals that provides the more accurate and precise position to GPS receivers used by civil users. At this time, permitting civil users to receive the more accurate signal is opposed by DoD.

While this would be a no-cost or low cost solution to the accuracy problem, a consensus has developed that even the more accurate GPS signal now protected by the DoD would not be accurate enough to provide for very low or no visibility approach requirements. The more accurate signal would provide accuracy to about 18 meters horizontally and 28 meters vertically. For now, visibility approaches, single digit meter accuracy would be required.

Aside from using the more accurate GPS signal, there are other means being considered to achieve the accuracy required for precision approaches. One approach would be to put more satellites up. As mentioned before, the GPS constellation is designed to make four satellites visible to a GPS receiver at any one time. To get the accuracy required, five or six satellites would be required to be "visible" to a receiver. To configure the constellation so this would be possible, would require that another four or five GPS satellites be launched. This would cost hundreds of millions of dollars. An alternative would be to put a smaller number of geostationary satellites in orbit that would likely provide the needed functionality at a cost of approximately $70 million.

One solution that is potentially less expensive is to use the Commonwealth of Independent States' satellite navigation system (GLONASS) to supplement the U.S. GPS satellites. GLONASS is very similar in function to GPS, however, there are some technical compatibility problems because GLONASS broadcasts on different frequencies and would require a different receiver than GPS.

Another potential satellite solution to the accuracy problem is to put a GPS navigation payload on other satellites to be launched. This is under active consideration by the international satellite consortium, INMARSAT, as it designs its next generation of communication satellites to be launched in the mid-1990s.

The technical solution to the accuracy problem that is gaining currency within the aviation community is establishing what is known as 'differential GPS stations' on the ground at airports. The concept is to provide an additional GPS signal from the ground that would be received in a local area 40–50 miles in diameter. This would provide enough GPS signals in the vicinity of an airport for a GPS receiver to achieve enough accuracy to make at least some, if not all, categories of precision approaches. Differential stations would be relatively inexpensive, costing approximately $100,000. Issues of who would own, operate and maintain differential stations (FAA, airports, or aviation users) would also need to be resolved.

Another technical issue that must be resolved before satellite navigation's full benefits can be realized is the "integrity" of the GPS system. Typically, aviation technology requires that equipment be reliable and redundant enough that there is negligible concern that the system is functioning accurately, and when it does not, that the fault or defect is immediately known to exist immediately by the humans involved so reliance on the faulty system can be dropped. The current integrity of GPS does not let the humans that known there is a fault for more than an hour, which is unacceptable from a safety standpoint. To resolve this issue, the FAA is considering systems to monitor satellite failures and issue warnings to civil aviation users.

Beyond making technnological choices of how to proceed with satellites, the FAA and the industry will also have to develop standards to which satellites, receivers, and associated equipment are manufactured and operated. While many pilots, particularly in general aviation, use GPS receivers to navigate, this use is unofficial and performed with equipment that does not meet FAA standards for functionality and reliability. FAA has recently issued certification standards for GPS receivers and the industry is expected to market receivers in the near future meeting those standards.

To receive full advantage of satellite technology, the FAA will also have to revise its air traffic control procedures and rules and develop new approach charts for satellite based navigation.

Also, new air carrier operational standards will have to be developed to incorporate satellite navigation into day-in and day-out airline operations. This includes cockpit procedures, and pilot training operational manuals. FAA has taken steps earlier this summer to approve GPS navigation as long as all other navigation was also installed and operative. At this point, it is approved for supplementary, not replacement, use.

All of these choices and changes will be coming at a time when the federal budget is under tremendous pressures to cut resources and staff. The FAA in particular is facing a freeze in FY 1994 which makes it very difficult to initiate new activity and programs. For FY 1995 the Administration is considering a budget option that would take $400 million out of the FAA Operations budget, a cut of approximately 8%. Whether such a cut would slow down progress to move the aviation system toward increased reliance on satellite technology, is undetermined.

There are a number of international institutional issues that will have an impact on the pace and extent of reliance on satellites for navigation beyond U.S. borders. Historically, standards for navigation equipment and navigation procedures are established internationally through the International Civil Aviation Organization, a United Nations body. ICAO, through its Future Air Navigation Systems Subcommittee (FANS), has agreed that the future international navigation system should be satellite-based.

However, there are concerns by some foreign governments that the basis of the proposed future satellite system is the U.S. GPS network. These foreign governments do not want the system to be controlled by any one country, and particularly not by the U.S. military. They are fearful that the global aviation community will commit to the U.S. system only to have it turned off at some point for U.S. national security reasons.

Beyond questions of control, some foreign governments realize that the aviation community is rapidly moving toward satellites and their electronics industries are oriented toward exploiting ground-based technology markets.

IV. FAA AND AVIATION INDUSTRY ACTIONS AND PLANS

Discussion and studies of satellite technology for aviation have been underway for 20 years, but concrete steps toward bringing the benefits on-line began approximately two years ago, when the DoD's deployment of the GPS constellation drew to a close.

In late 1991, the FAA commissioned the RTCA to form a task force to develop a strategy for early implementation of a global satellite navigation system. (RTCA is an association of aeronautical organizations, government and private, that seek to develop technical solutions in the application of electronics and telecommunications to aviation operations). In September, 1992, the RTCA Task Force issued a detailed report on how the various technical issues associated with the introduction of satellites into the aviation system should be approached and resolved.

In late 1992, the Federal Aviation Administration established a Satellite Program Office to establish goals and a program to implement such goals. This office has published a plan with timelines and milestones to implement many of the RTCA Task Force recommendations. Without detailing all of the activity underway, some of the highlights are the following:

FAA plans to complete the necessary steps by the end of this year regarding certification and approval of procedures for the use of GPS as a supplemental navigation system, including non-precision approaches. As part of this goal, the FAA earlier this year issued aeronautical certification standards for GPS receivers, and some operational/navigation procedures.

FAA plans to take steps to provide for limited visibility precision approaches (Category 1) using GPS by the end of 1994 for general aviation, and mid-1995 for commercial operations.

FAA plans to determine the feasibility of using augmented GPS technology for Category II and III precision approaches (very limited and no visibility situations) by mid-1995.

FAA plans to approve GPS for navigation as part of automated cockpit flight management systems over the ocean in mid-1995.

FAA's current plans are to approve use of GPS as a primary navigation system in the domestic en-route and terminal environments in the year 2000.

The Department of Transportation and the Department of Defense have also established a Task Force at the Office of the Secretary level to coordinate activities related to civil use of the military system, including co-ownership between FAA and DOD. This task force is to report back with recommendations next November.

Also, over the past two years, the airline industry has been involved in a variety of tests of satellite navigation and communications in conjunction with the FAA, particularly over the Pacific Ocean. This testing is expected to continue and to expand.

FUTURE USES OF SATELLITE TECHNOLOGY IN AVIATION

WEDNESDAY, JULY 28, 1993

House of Representatives,
Subcommittee on Aviation,
Committee on Public Works and Transportation,
Washington, DC.

The subcommittee met, pursuant to call, at 10:40 p.m., in Room 2167, Rayburn House Office Building, Hon. James L. Oberstar (chairman of the subcommittee) presiding.

Mr. Oberstar. The Subcommittee on Aviation will come to order.

The year was 1926, the dawn of civil aviation. There was great excitement about the beginning of commercial air service as the U.S. Post Office launched aviation with its famous mail contracts.

One of those early airmail contract pilots, Jack Knight, was frustrated at not being able to do more work and could not accept conventional wisdom that you cannot fly at night. So he organized farmers along his route from Kansas City to Chicago to light bonfires at certain times along the way to illuminate his flight and prove that you could navigate aircraft and fly commercially at night. It worked.

It wasn't long before bonfires were replaced by lighthouses. And in a subcommittee hearing room upstairs, the second floor, there is a display of the early lighthouse service. Some moved inland, to guide aircraft as well as ships at the water's edge.

From lighthouses, technology quickly moved to radio beacons, and we now have a network of 1,325 radio beacons across the United States.

In 1982, some 56 years later, President Reagan startled and challenged the aviation world with a proposal to make a global positioning satellite navigational capability available to the world of aviation through ICAO at no cost to users. But this exciting innovation, while viewed with excitement by the aviation community, was viewed with some alarm and perhaps concern by our competitors and our friends abroad who saw this as a massive U.S. leap of technology into the future way ahead of them; secondly, a concern that technology would be controlled by the Defense Department and perhaps might not be available at times when they might need it.

And there was great skepticism, unfortunately, by other nations, toward this proposal. Not to be left out, the Soviet Union moved very quickly shortly after that with its GLONASS, Global Navigational Satellite System. And the age of navigation by satellite was under way.

In many parts of the world, there is little or no ground-based navigation system for aviation. In those parts of the world, satellites can provide the navigation we need—that pilots need with accuracy and dependability but without the need to build costly, on-the-ground navigational infrastructure.

One of the staff members of the Aviation Subcommittee, who spends a good deal of her time in remote parts of the world on her own vocation, like climbing the mountains of Africa and the jungles—exploring the jungles of South America, and working with chimpanzees, piloted an aircraft over a remote part of Bolivia that on navigation charts appeared as white, uncharted territory on her aeronautical navigation chart; but using a GPS receiver, Caroline was able to find a remote strip in the new national park in Bolivia hundreds of miles from where she took off.

The potential benefits such as these and many others that can be realized from global positions satellites will be translated into reduced costs to government, reduced costs to the aviation industry, greater efficiency, greater dependability, and eliminating the need for other costly technology now under development.

If precision approaches can be achieved with satellites, the FAA's Microwave Landing System, for example, when it comes to a decision point in 1995, might be abandoned. But certainly there will be a competition between now and then in the development of these two technologies. But even if that one step could be avoided, there could be a savings of over a billion dollars.

Aircraft will be able, with GPS, to operate closer together and travel more safely, particularly over the ocean, achieving millions of dollars in savings in more fuel efficient routes. And as one of these displays will show, if your en route capability can be developed with reliability that is now expected, there can be en route flight plan changes that can take advantage of the jet stream and move aircraft faster to their destination saving 20 to 30 minutes in oceanic travel and give greater reliability.

As one of those displays show, a pilot actually thought he was further south on his route than the GPS actually placed him and he avoided making a very costly and perhaps dangerous mistake.

Part of the excitement about satellites and aviation is that much of the technology to be used in the system is already developed and in place.

As of last month, the Defense Department's Global Positioning System Satellite Constellation was completed. Research and development is still under way and needs to be pursued, but the satellites are launched and they are operating.

It appears, from a civil aviation perspective, that we do not have to proceed with the standard lengthy frustrating invention, development, perfection, testing process that has so often attended other technology.

In addition, the FAA took steps earlier this year to specify standards for GPS equipment and has published operational procedures. I believe that it will be clear by the end of this hearing that the FAA has moved more decisively, more speedily, and with more of a vision of the future on this technology than they have on any other technology the FAA has worked with.

There is a real excitement and enthusiasm not only within the FAA but also within the aviation community for the GPS technology. That is not to say that all of the problems are behind us. Clearly, in anything this technical, this complex, there are technological questions. But they are being addressed. Particularly, the rather disturbing issue, one that I think is of some concern—and we will explore this in the hearing—is that of reliability or integrity of the GPS system; its reliability to be dependable at all times under all conditions in all parts of the world.

There are other problems that maybe are more institutional in nature, such as how the FAA, the DOD, and international bodies, ICAO, other countries that want to develop similar technologies, such as the European Community, are going to react to this technology and integrate it into their thinking and into their formal rulemaking.

Many of our competing nations, world partners, particularly the Europeans, are focused on ground-based systems. If the United States moves precipitously and with full vigor on a GPS system, it will leave their technology in the dust—star dust, to be sure and they will have lost an important opportunity in the world market. They are, obviously—and I think for commercial purposes, going to be dragging their feet.

So we look forward with a great deal of excitement to the testimony and the information that will be presented, both by the FAA and by our many user witnesses, technology witnesses. And I urge all members to take and all participants to take a look at the technical displays around the room.

I ask unanimous consent that the staff briefing paper be included in the committee hearing record at the outset following my statement and that of Mr. Clinger.

But I think it is the most complete documentation of evolution of this technology available today.

The Chair now recognizes the gentleman from Pennsylvania, Mr. Clinger.

Mr. CLINGER. Thank you very much, Mr. Chairman.

Satellite technology, especially the Global Positioning System, promises to save aviation users tremendous sums of money through the use of more efficient point-to-point routing, as well as through the consolidation and elimination of ground-based aids to navigation.

Satellite technology has the very real capability of providing a win-win to government and to industry, lower operating costs and greater reliability to the Federal Government and better routes and global coverage for industry.

I do worry, however, about the FAA's ability to bring this technology into the mainstream.

First, understandably, the agency is very, very cautious about testing, certifying, and standardizing the engineering protocols inherent in any complex navigation system. And for this, I don't fault them. I would encourage them to work as expeditiously as possible to reach closure.

Second, the FAA is going to have to decide how it intends to continue with the Microwave Landing System.

And, third, the agency must, in the meantime, continue to procure conventional instrument landing systems for installation at airports until it is prepared to bring GPS to the forefront.

FAA must, therefore, be judicious, balancing the costs associated with current needs for new systems against future costs of shifting away from the technology to GPS.

In addition, I worry about the ability of our government to work together with major foreign governments and industry to develop a common set of engineering standards for satellite-dependent technologies, which you referred to.

News of ICAO's recent decision to not sanction the Global Positioning System as a viable program is particularly disturbing. We now have in place a constellation of satellites. Yet the implication of ICAO's decision, appears to suggest their desire to field an entirely new system of satellites at tremendous cost and delay.

Aircraft and radio manufacturers are anxious to incorporate these devices in airplanes. We need to come to an agreement very soon, otherwise we face the very real specter of witnessing the development of several competing, incompatible technologies being incorporated in aircraft. Something that none of us would like to see happen.

The result will be tremendously increased costs to air carriers as they equip their international fleets with several varieties of navigation and communication radios. Despite ICAO's view, I believe that we must continue to assure our international aviation partners that the reliability of the GPS will not be subjected to military manipulation, that it will be truly an international, civil, navigation system.

Finally, I believe the costs associated with GPS must be resolved in such a way that the FAA can continue to afford this technology. The expense associated with launching new satellites to replace those now flying can become prohibitive very quickly; and so long as the military is advantaged by GPS, I am convinced they should share the burden no matter how intensively civil users rely on this system.

I want to thank our witnesses for taking time from their schedules to appear before us today and particularly Secretary Peña for being with us. I appreciate your appearance and look forward to your statements.

Thank you, Mr. Chairman.

Mr. OBERSTAR. Before we proceed, I would like to insert into the record at this point statements received from Representative Costello of Illinois, Representative Collins of Michigan, and Representative Blackwell of Pennsylvania

[Statement referred to follow:]

STATEMENT OF HON. JERRY F. COSTELLO

Mr. Chairman, I want to thank you for calling today's hearing to discuss the future uses of satellite technology in aviation. I also would like to welcome Secretary Peña and the other witnesses who will testify today on this subject.

I believe the possibilities of the Global Positioning System (GPS) technology are very promising to the aviation community. Although there are a few concerns that must be considered, I expect these issues will be raised during today's hearing and fully understood prior to any decision-making by this committee or by the Federal Aviation Administration.

I look forward to hearing the testimony of today's witnesses on the GPS system and I hope you will educate us on both the positive and negative aspects of this technology. Mr. Chairman, I want to thank you again for calling this hearing and for your leadership on this aviation issue.

STATEMENT OF HON. BARBARA-ROSE COLLINS

Thank you, Mr. Chairman for holding today's hearing on the future uses of the global positioning system satellite technology in the aviation industry. This technological innovation, which is within our grasp, could potentially revolutionize air travel well into the next century. The magnitude of GPS's impact is almost immeasurable, since it offers us the possibility of fundamental change in aircraft operations.

I am particularly intrigued by its implications for enhanced capacity and efficiency at our major and congested airports. Given current budget constraints, and reduced appropriations for the FAA operations account, I wonder if this new system will be available for broad commercial use soon. I am sure that after today's testimony, we will all have a better understanding of where we stand today, and how long it will take to implement this technology.

I greatly appreciate the testimony of our witnesses this morning. I would also like to thank Secretary Peña for his attendance this morning, given his busy schedule today. I am confident that he will be able to give us a clear understanding of the administration's views on FAA use of the GPS system, and possible restructuring of the ways in which the FAA will best utilize its resources to implement satellite technology.

Again, Mr. Chairman, thank you for convening this hearing. I believe it is a further testimony to our subcommittee's commitment to ensuring a safe and efficient aviation industry for the twenty-first century.

STATEMENT OF CONGRESSMAN LUCIEN E. BLACKWELL

Thank you, Mr. Chairman. I am pleased to join you and my colleagues as we prepare to receive testimony on the future uses of satellite technology in aviation.

The growth of air commerce—both national and international—to the United States communities is fundamental to the revitalization of the United States economy as well as local and regional economic development. Air transportation is both a cause and effect of the development of this global marketplace. That is why any changes to the aviation system brought about by satellite technology will be far-reaching.

This technology—as I understand it—will provide new and improved prospects for greater accuracy and timeless of aircraft position information as well as basic changes in how aircraft operations and associated procedures are managed. Many corporations and organizations will have a direct interest in the development of this technology. The resulting interplay of commercial interests in the air transportation business—airlines, aircraft manufacturers, suppliers, labor unions, financial institutions—and public agencies responsible for aviation infrastructure, federal, state and local governments as well as airport operators will be impacted significantly by this implementation .

There are a number of unanswered questions about the potential effectiveness of initiating this system. I am sure that today we will hear many suggestions offering clever approaches for integrating this much talked about technology. As we ponder the issues today, I favor the view that the perfection of this technology is a sound approach.

It is a well-known fact that airports are still trying to catch up with the dramatic air traffic growth and capacity demands of recent years, but, regrettably, each year they seem to come up short. Perhaps, the use of satellite technology will heighten the effectiveness of airport operations. Through the use of satellite technology, perhaps we can now move ahead to reduce operating delay costs associated with flight time and fuel consumption, low productivity and poor capacity.

With a more intense focus on improving the current system, we must strongly consider the potential benefits of this technology. Through its implementation, I envision a great enhancement of our transportation system.

Mr. Chairman, in light of the gravity of the circumstances surrounding the development of satellite technology and the policy choices facing government and industry as satellites are brought into the aviation system, I welcome the witnesses who will appear before us this morning and look forward to hearing their testimony.

Thank you, Mr. Chairman.

Mr. OBERSTAR. Thank the gentleman for those cautionary remarks.

In light of the Secretary's presence with us this morning and his schedule, the Chair would ask other Members, with the exception of the gentleman from Pennsylvania, Mr. Shuster, the Ranking Member on the full committee, to withhold their statements.

The Chair recognizes the gentleman from Pennsylvania for his statement.

Mr. SHUSTER. Thank you, Mr. Chairman. I will be brief. I welcome the Secretary.

Based on my experience as the Ranking Member on the Intelligence Committee, I bring enormous enthusiasm to the potential of using satellites in navigation and communication for aviation systems.

What we might formerly have thought of as Buck Rogers-type scientific fiction is reality today. During Desert Storm, halfway around the world, we were able to track and listen to Iraqi tank commanders down to the individual tank. This capacity exists today. The task now, of course, is to commercialize it. The research has been done. The task is to commercialize it and create the standards that can be used internationally. And so I strongly support our effort.

Thank you very much.

Mr. OBERSTAR. Thank the gentleman.

And I would also announce that following the Secretary's statement, I would ask Members to search their souls if they have some really burning question that must be asked, and we will give those who have such a question a minute. The Secretary does have another commitment to which he was long ago committed, but he changed his schedule to be with us this morning.

And we welcome you and your first appearance before the Subcommittee on Aviation, Mr. Secretary.

TESTIMONY OF HON. FEDERICO PEÑA, SECRETARY, U.S. DEPARTMENT OF TRANSPORTATION

Secretary PEÑA. Thank you, Mr. Chairman and Members of the committee. And let me applaud you for having this hearing. This truly is a new and exciting technology for our country.

And, Mr. Chairman, I appreciate your recognition of the fact that I was not originally scheduled to testify here. But when I had personal notice of the subject matter, I wanted to be here. And let me tell you why.

Immediately upon taking office as the Secretary of Transportation, I think within 30 days, I had my first meeting in the Department to focus on this new technology because one of my priorities in the Department of Transportation is to bring new technology to transportation services in our country, and also because of some of the questions that were raised in the opening statements.

I was hopeful that by focusing on this issue very early and elevating it, we could have much more progress.

As a result of that, Mr. Chairman and Members, I am happy to report that, early on, Secretary Aspin and I convened a joint DOD/DOT task force which has been attempting to address the issues that some of you raised in your opening statements; and we are hopeful that sometime this fall we will reach agreement on some of those questions. I am very happy to be here to tell you that this is truly a technological achievement which I believe will produce major benefits for industry and for commerce in our country.

As civil use experience with our satellite-based global positioning system develops, these benefits may extend to mass consumer markets affecting a large portion of U.S. households. Because of the nature of this technology, benefits have already been extended to the far corners of the world, extending the goodwill of the people of the United States in a way that was never before possible.

With me today are two gentlemen whom I believe many of you already know. They will present to you detailed information on FAA's planning, research, and development for aviation use of the Global Positioning System. They are Martin Pozesky, the Associate Administrator for System Engineering and Development and Anthony Broderick, the Associate Administrator for Regulation and Certification in the Federal Aviation Administration.

GPS, which was initiated in the 1970s, is a space-based positioning and navigation system. GPS signals are continually available on a worldwide basis in any weather. The satellites are located 11,000 nautical miles above the earth. To access the system, the users have only to turn on a GPS receiver, like those on the witness table, which is like a normal radio, with the antenna exposed to the sky.

GPS provides the greatest opportunity to enhance the air navigation system since the introduction of radio-based navigation more than 50 years ago. Satellite-based navigation represents an economic benefit to the U.S. aviation industry, perhaps involving billions of dollars a year.

The civil use of GPS for oceanic and domestic en route flight offers significantly better navigation accuracy than previously possible. When combined with other systems, it will allow a pilot to fly an optimum route to a destination—the example that you alluded to earlier—subject to only the weather and the presence of other aircraft in the area. This will provide considerable time and fuel savings in managing en route air traffic.

GPS has a wide range of applications in other transportation sectors. That is why I wanted to be here today, Mr. Chairman, to talk about the broader possibilities here in the space program and growing commercial space industry. For example, GPS is used to satisfy positioning and timing requirements for earth-orbiting space systems, including Space Shuttle operations.

GPS will provide marine navigators with the first precise worldwide continuous positioning and timing service. As a result, commercial shipping will be safer, more efficient, reliable, and economical.

GPS, augmented with differential signals, will satisfy the stringent marine accuracy requirements for harbor and harbor approach navigation, which has previously been unattainable with other navigation systems.

Land applications are expected to comprise the largest category of GPS users. While today's attention is focused on the aviation side, the land side really gives us the greatest potential. Although not traditional radio navigation system users, they are expected to employ various systems being developed to enhance the economic efficiency and safety of all land modes of transportation.

Let me give you a few examples:

First of all, Intelligent Vehicle Highway Systems will combine GPS with communications, controls, navigation, and information systems to improve highway safety, ease traffic congestion, and reduce harmful environmental effects.

Today there are a number of cities in our country—Denver, my hometown, for example—which are using these kinds of technology in their buses as we track buses through our cities and hopefully improve their timing by locating those buses as they travel throughout the Denver metropolitan areas.

Vehicle tracking systems will use GPS for commercial and transit fleet management, hazardous material monitoring, tracking and controlling movements of railroad equipment and automated dispatching of fire, paramedic, and police units.

GPS is used in surveying, telecommunications and electric power synchronization, agriculture and forestry, census taking, meteorological radiosondes, and even backpacking.

In fact, Mr. Chairman and Committee Members, last year, when Denver started to build its new baseball stadium for the Colorado Rockies, home plate was identified by the use of satellite technology; and we were able to save two-thirds of the time it normally takes to locate home plate. I hope the Rockies play as well.

It is too early to say whether consumer markets will develop to the point where a GPS receiver is as commonplace as the radio receiver is now in private automobiles. However, it is clear that if such a market does develop, we are looking at very large numbers of installed units and individual users.

The U.S. Coast Guard has established a unit to provide support and assistance to civil users of GPS, including both transportation and nontransportation applications. The Coast Guard is proceeding with research and development for implementation of GPS for marine users. The Coast Guard's efforts, along with those of FAA, are providing the leadership necessary to promote the full civilian use of this exciting technology.

GPS is being implemented by the Defense Department at a cost approaching $10 billion. Even before becoming operational, GPS proved its worth to the national defense in Desert Storm.

However, because of its potential value to civil users, and in recognition of the significant national security implications that might be associated with widespread civilian availability, Secretary Aspin and I formed a task force to study the future management of GPS. We want to assure that the full potential civil benefits are, in fact, made available to the public, while preserving—and I want to emphasize this—while preserving the national security benefits of GPS for military uses. I expect to receive the task force recommendations this fall.

Mr. Chairman and Committee Members, I commend your interest and support and enthusiasm for this important subject. We look forward to working with you to assure that the full benefits of GPS are rapidly available to civil aviation and the entire transportation industry.

Thank you very much Mr. Chairman.

Mr. OBERSTAR. Thank you, Mr. Secretary. We do have a vote in progress. I did want to ask you about the task force report.

Is there anything determinative about it? Is it just a report on the status of technology in progress?

Secretary PEÑA. No. The principal focus is to attempt to address this question of defense versus civilian control of the system.

Mr. OBERSTAR. Okay.

Secretary PEÑA. And we are hoping that we can address that issue in addition to some of the other technical issues so that we can give the civilian users the kind of confidence they need that the system will be available over the long term.

Mr. OBERSTAR. That would be very important, as I noted earlier, in our international dealings and as Mr. Clinger noted in his opening remarks.

Mr. Secretary, this is the easiest the Secretary of Transportation has ever gotten off in this subcommittee. I won't say that you were saved by the bell, but the timing was absolutely marvelous, and your statement was right on track; and we appreciate it.

But most significantly is your own determination to be here on your own. We didn't ask for your presence. We only do that when we feel that there are matters of high importance that require Secretarial attention. But it is a tribute to you and your leadership of the Department that you wanted to be here to address the importance of GPS, not only for aviation but, as you so well laid it out in your statement, for the intermodal implications and effects of this technology. Thank you. And continue your great leadership of that Department.

The subcommittee will stand in recess pending this vote.

[Recess.]

Mr. OBERSTAR. The subcommittee will resume its sitting.

Would people be so good as to close the doors to eliminate the hall noise.

I thank the volunteers.

TESTIMONY OF MARTIN T. POZESKY, ASSOCIATE ADMINISTRATOR FOR SYSTEM ENGINEERING AND DEVELOPMENT, FEDERAL AVIATION ADMINISTRATION; AND ANTHONY J. BRODERICK, ASSOCIATE ADMINISTRATOR FOR REGULATION AND CERTIFICATION, FEDERAL AVIATION ADMINISTRATION

Mr. OBERSTAR. Mr. Pozesky, welcome. And, Mr. Broderick, welcome. We are glad to have both of you, the dynamic duo of the FAA. It seems that the two of you are always in the forefront with challenges as well as opportunities for the FAA. We are very pleased that we have your leadership, your expertise, and your dedication to aviation at the forefront of this very important agency.

I want to add—which I intended but neglected to do in my opening remarks—that all too often the focus in this country on technology is on NASA and the Space Shuttle and now the Space Station. And time again, it is a big deal to see on TV the liftoffs and the exploits in space. And all of that glamour tends to overshadow the far more complex, far more difficult technology that the FAA develops and operates, which is of infinitely greater importance to most Americans than is the space program.

While the man-orbiting satellites, Space Station will accommodate some six people, at max, the FAA operated system is moving half a million people, roughly—half a billion people boardings and so on yearly in the United States. Nearly half of all the people who travel by airplane in the world, travel in the United States under the FAA's guidance and under the command of all this complex technology. And I think people ought to understand the significance to our national economy that this relatively small but important and highly motivated, agency represents.

A critical factor in a $600 billion of our sector of our 6 trillion economy, it is in your hands.

Mr. Pozesky, please proceed.

Mr. POZESKY. Thank you, Mr. Chairman and Members of the Subcommittee. Thank you again for the opportunity to appear before you and most importantly for the leadership and the support you have provided and support of FAA activities in this program area.

Mr. Chairman, we are here, of course, to talk about satellite technology and GPS. There is no question that GPS has far-reaching potential for the future of aviation.

Two years ago, GPS was beginning to mature but was still only a hope. Today we are well on our way to having a single navigation system that can handle all phases of flight all over the world with unprecedented accuracy.

GPS, combined with advanced telecommunications and higher levels of automation, offers unlimted opportunities for improvement in aviation safety, capacity, and efficiency.

There is no question that major benefits exist for the airlines. These include fuel savings, reduced flight time, reduced avionics requirements, more efficient flight paths, and reduced delays.

These benefits are more likely to be realized over the ocean, where a combination of GPS positions, relayed back to the ground, can provide a radar-like surveillance capability to the air traffic controller. This can enable us to put the aircraft on the "best-wind" positions as they cross the ocean.

There are major benefits in terminal and en route as well. As dramatic as the airline benefits are, there is no question that general aviation may achieve even more benefits from this capability. The real possibility exists to provide precision and nonprecision approach to virtually every airport in this country through a combination of these systems.

Both general aviation and commercial carriers will enjoy far greater operational flexibility by having these additional instrument approaches available to them.

Tony and I are strong advocates of GPS. What is also very exciting for us, however, is the fact that the FAA has played a leadership role in the application of this exciting new technology to aviation. The FAA has approved the supplemental use of GPS for all phases of flight, including nonprecision approaches to airports.

With this approval, GPS can be used to fly existing VOR, NDB, and RNAV approaches. In tests undertaken in conjunction with Transport Canada, FAA has tested and approved instrument approach overlay procedures that will permit nonprecision approaches at over 2,500 airports in the U.S. And we have issued certification criteria for these GPS receivers, which are expected to be available for U.S. manufacturers this fall.

By the end of year, we anticipate that DOD will declare the initial operational capability for GPS. However, even before this formal declaration, we have begun to use GPS in the domestic and oceanic airspace.

Frankly, I believe that, by any reasonable measure of achievement, we have made significant progress. In fact, I must tell you that this is the first time that I can remember that the FAA has had procedures in place for new technology before the certified avionics have become available.

Let me state quickly, however, that we are well aware of the need to continue this progress, not alone, but in a coordinated way with the aviation community.

While we are both satellite enthusiasts, please be assured that we are mindful of the safety implications of this system and are taking all necessary steps to ensure that the future system will be at least as safe and reliable as the systems that have served us so well over the past decades.

Nonetheless, it is absolutely true that the system has the potential of providing substantially more capability at enhanced levels of safety and integrity through the proper mixture of satellite technology, separate integrity and monitoring systems data links, cockpit, and ATC automation.

I ask that the Subcommittee focus again on the combination of technologies because that is what is really needed—GPS for precision navigation, data link for error-free computer-to-computer communications, and ATC and flight automation to develop the needed capabilities for all elements of aviation.

The movement to this new technology must be done in a coordinated way with the entire aviation community.

About 18 months ago, FAA asked RTCA to be the forum for the development of a U.S. aviation industry-wide consensus for moving towards satellite navigation. That landmark effort was completed in September of 1992, and resulted in broad community support for early transition to GPS and satellite technology.

In fact, we expect to make continued use of RTCA, as well as numerous other coordinating mechanisms to help this whole transition move ahead. You hear in these hearings of the need to continue that coordination, and we are very mindful of that.

It seems, however, that we can never do enough to ensure that the whole effort proceeds in close coordination. There is a lot of activity under way, and now there will be more to follow.

I would like to talk a moment about the international scene. We have been working with ICAO to foster the introduction of satellite technologies for worldwide aviation applications. ICAO has decided to develop what it calls a Global Navigation Satellite System, or GNSS. It looks like it is going to take ICAO some time to finally decide on the details of its international system.

So in an effort to get on with the early introduction of satellite technology for aviation, the U.S. Government formally offered the Standard Positions Service component of GPS to ICAO as a transition step to enable early movement toward satellite navigation while their GNSS is being defined.

Over the next years, you are going to hear a lot of discussion of both GNSS and GPS. It is important to understand at least the conceptual difference between those two systems. GNSS, the Global Navigation Satellite System, is the ICAO system. Its full definition may take many years. ICAO probably won't be satisfied with just a technical definition, but it is not going to get into issues of institutional and legal arrangements before full implementation.

Ultimately, we believe that GNSS will be made up of a mix of systems provided by the individual states, of which GPS will be a component.

Nonetheless, Mr. Chairman, we should not wait for GNSS in order to get on with GPS. There is no question that we want to move with the international system as rapidly as we can, and we will push ICAO to do that. But even our most optimistic estimates of time frame are not very optimistic. While GNSS is evolving and being defined, we can capture the benefits of GPS in parallel and believe that that can be done in a way that GPS will be a compatible part of any future system or at least a stepping stone to the future system.

There has been confusion about this posture and confusion about what is going on internationally. The article that appeared in some trade press yesterday did not indicate that ICAO has rejected GPS. In fact, what the article really meant to say was that ICAO is trying to deal with what is going on beyond the time frame of GPS.

This is going to be a continuing issue with us, and we will explore that in the course of these hearings. In the long term, there are still a number of legitimate policy and technical issues to address as we begin to rely on this new technology, and begin to make plans to phase out the old systems.

You have heard from the Secretary on efforts underway at senior levels to assure that GPS is a National system, usable to all modes of transportation, not just aviation.

What we need is a government strategy, not just an FAA strategy; and we are well aware of that. The military mode of GPS is reserved for defense applications and for national security reasons, and has not been made generally available.

The civil mode, what is called the Standard Positions System, is available to any user. The basic system will provide significant improvement over existing methods of navigation but will need augmentation to meet the full range of anticipated civil needs.

To provide this, we are developing a system called Differential GPS, which will enhance the accuracy of GPS for all users within coverage. It will correct for errors in the satellite signals and transmit error correction messages directly to the aircraft receivers.

GPS, with this differential capability, should allow precision approaches at a very modest cost at virtually every runway end in the world. Think of it: every runway end in the world, at a very modest cost.

In fact, we brought with us one of the black boxes that might be required at an airport to require that capability, the so-called "local differential." It is a very small device, significantly less expensive than an Instrument Landing System, and conceivably, could provide approaches with a single device, as opposed to need for separate devices at each runway end.

Mr. POZESKY. We are even exploring the application of GPS to airport surface operations for pilot navigation around the surface of an airport. Even an improved GPS-based TCAS, which we have begun to call TCAS IV, is clearly possible with this technology.

Again, in order to move ahead in a coordinated way, we are currently, through RTCA and with the community, on what we call Task Force Two, which will result in community agreement on a standard design to use these differential systems.

We have purchased some local systems for initial use and anticipate asking for full implementation funds as soon as we get these standards systems agreed to and a design finalized.

In the longer term, we see many exciting possibilities. We are continuing R&D on the ability of GPS to support such functions as weather prediction, airport surface navigation, height monitoring over the oceans, even aircraft attitude—and I mentioned TCAS—to name only a few.

The actual development of the operational procedures and standards is a primary function of what we call our FAA Satellite Operation Implementation Team, or SOIT. This team was formed in 1991 to do the operational work and get us ready for the early achievement of the GPS capability. SOIT's aggressive pursuit of this early capability has resulted in the development of these TSO's which redefine the minimal operating performance standards to permit navigation, thus increasing GPS effectiveness.

Mr. Chairman, this is an exciting time. We are pursuing the technology as rapidly as possible and being mindful of the need to take the necessary steps to ensure the system will be as safe and reliable as the systems that have served us so well over the past decade.

I have personally never witnessed so much excitement and enthusiasm, either inside the FAA or in the aviation community, about the rapid adoption of this technology. And I can assure you that the FAA will remain in the forefront of that movement.

Thank you again. Tony and I would be pleased to respond to your questions.

Mr. OBERSTAR. Thank you very much for a splendid and comprehensive review of the technology.

Mr. Broderick, you don't have a separate statement?

Mr. BRODERICK. No, sir.

Mr. OBERSTAR. All right. It has been said by other observers of the scene that, to make this system fully effective and functional, you are going to need an automated data relay system to the cockpit so that digital information will show up in the cockpit in addition to the voice transmission.

Often voice transmissions get confused or are not followed appropriately or people forget the information. But a digital read out in the cockpit, on a computer will make it less likely that there will be mistakes made.

An automated traffic management system is a concept that has been advanced and is being developed.

Where does that stand in relationship to the progress we are making on GPS?

Mr. POZESKY. Mr. Chairman, there is no question that that is correct. GPS, by itself, will provide navigation; but the full benefits require this data link.

Again, we are talking about a technology that has already been invented. There are many data links around from which we can choose to do this job.

The key is to get a community agreement on which data link we are going to use, so that the differential information provided at each airport is provided in the same way so that the aircraft don't have to carry five, six, seven, or eight different kinds of data links.

That is what RTCA is now working on with us, Task Force Two. One of their first products will be a recommendation on which of those data links we need to use for this differential correction capability. And we will move very rapidly with that.

Today we can provide that capability through a number of different ways. Our objective is to go to an industry-wide standard so that we can all be assured we won't have throw-away equipment. And we hope to be able to be in that posture by this fall and move out rapidly on a standard design for all of aviation's data link application.

Mr. OBERSTAR. Thank you. I appreciate the FAA's approach to technology, proving it out, taking the time, making sure it is going to work, making sure it works under all the stressful and varying kinds of conditions.

But some say, as so often in the past, that it isn't moving fast enough or broadly enough on this or the other technology. In this case, I think you have got regulations already in the works before the technology is in place. I think you have moved much faster, as I said in my opening remarks, than on most other technologies.

Are there some aspects of the program that can be accelerated? And what resources would you need to do so?

Mr. POZESKY. Mr. Chairman, we are continuing to search ourselves to answer that question.

I would be wrong if I told you that there was no possible way to accelerate this effort. We are looking for that every day of the week.

We have, for example, just last week, decided to begin to write the detailed specifications for this differential system, kind of leaving a blank for the data link so we can fill this in when we get the information and get our internal process started.

The funding right now is adequate for us to proceed. We are moving rapidly. We are constantly talking about ways to accelerate this program, and I cannot, at this sitting, identify anything more that we should be doing that we are not. That is not to say that we won't identify something a month from now or two months from now and try to move that rapidly. But at this time, I have to honestly say that we are moving as rapidly as is prudent to pursue this technology.

Mr. OBERSTAR. Thank you very much. I will withhold any questioning until later.

Mr. Clinger.

Mr. CLINGER. Thank you, Mr. Chairman. And, gentlemen, thank you for your testimony.

Apparently, the trade press was a little misleading. I had gleaned from it that you all were disappointed that decision was taken by them. Can you clarify?

In other words, you are now saying that the GPS will be part of an evolving system, that it is going to presumably remain compatible with the international system that is going to take much longer to develop and have in place.

Mr. POZESKY. Let me try to take a minute and try to describe that because, again, there has been lots of confusion. I read the article myself, and I came to exactly the instantaneous conclusion you came to; and I had to go check it out and find out what the background was. So there has been confusion about what is going on internationally.

ICAO has a committee which was called FANS, Future Air Navigation Systems, which is defining the standard ICAO, let me use that term, satellite system.

That committee is defining the characteristics and has recommended that the GNSS system incorporate GPS and any other satellite system that other entities may provide. The Russians have a system that may or may not be a part of this system. There are other nations that are talking about launching a satellite.

So where ICAO is moving is to adopt an overall architecture which will make use of new systems as they are fielded, as they become available. That is the general strategy.

What that article was talking about yesterday was a paper that was written about what do you do when GPS may not be available any longer. It was a very, very far-reaching paper, trying to look generically at the characteristics of an ICAO system.

But ICAO has not disregarded or rejected GPS. In fact, I think virtually everyone I talk to wants to get on with using GPS and take advantage of the capability while this international definition is going on.

Mr. CLINGER. Thank you. That is somewhat reassuring, I think, from what I have been led to believe.

Could you talk a little bit about the dilemma with regard to MLS and GPS if, in fact, GPS is going to be in a position to do precisely what MLS is designed to do?

How do we resolve that, in other words, and still keep within the international agreements with regard to MLS?

Mr. POZESKY. I will start, and Tony can join in and help here. First of all, let me say there is no question that the MLS–GPS–ILS dilemma is just that, a dilemma. GPS offers a great deal of potential. And the key revolves around just how far up the precision landing ladder we can go with this technology and still have confidence.

As you know, precision landing capability comes in three flavors: Category I, Category II, and Category III. There is no question in our mind that the first level Category I capability can be provided by GPS. In the U.S., that is a big deal because of the roughly 1,000 Instrument Landing Systems we have, 700 of them Category I. So that would be a big payoff for us.

Internationally, for example, in the U.K., they don't have any Category I landing systems. All of their landing systems were low-visibility Category II, Category III. So they need to get GPS to a higher level of capability before they can say they have no need for MLS, if they were ever to say that.

So there is a genuine dilemma on how far up this ladder we are going to be able to push GPS, We are doing R&D right now to develop Category II and III capabilities for GPS, as well as Category I. But we are not across the finish line yet.

We are going to have to proceed with both technologies until we either decide that we are not going to get to where we want to in the very near term with GPS or we get across the finish line.

We are targeting 1995 as to when we will have that answer. In the meantime, we need to continue the development of both systems until we have that answer.

Mr. CLINGER. Some have suggested, where the satellites are going to be in position and ready to go, that the flight procedures that you are charged with developing are not going to be ready to go. Is that a problem?

We talked a little bit about that already. Hopefully we are going to coordinate its development so that we won't have a system in place that we can't use.

Mr. BRODERICK. Absolutely. What we are trying to do, Congressman, is take advantage incrementally of GPS technology as we can.

We started out, for example, with en route capabilities being approved for what was called a multisensory system where GPS was only one of the inputs.

We have then gone to an overlay program and an en route program with the TSO we now have out, which enables you to build a GPS receiver and put it in an airplane and have it certified for all en route operations and all nonprecision operations.

You are right, we need to work on procedures; and we are doing that incrementally. We have air traffic people literally housed with the SOIT that Marty talked about; the operational implementation team is working daily on that.

The benefit of GPS is not in the technology, but it is in the use of the technology with procedures. We are acutely aware of that and working on it every day.

Mr. CLINGER. Thank you.

Thank you, Mr. Chairman.

Mr. OBERSTAR. Mr. Geren.

Mr. GEREN. Thank you, Mr. Chairman.

In your testimony, the written testimony, in the way you talked about the outstanding cooperation that has been between the DOD and FAA in this area, are there further opportunities there for cooperation?

Obviously, this is a technology with tremendous military application as well as civil aviation application. And I just wondered if there is more that can be explored there, and perhaps that is something the Armed Services Committee ought to also look into to see if this is something that this cooperation could be expanded and built on.

Mr. POZESKY. The simple answer is, yes, there is a great deal more that is being looked at for joint civil-military cooperation.

But I would like to take the opportunity to say very simply that I, at least, am sensitive to the fact that the folks who invented the GPS system 20 years ago put a civil mode into that system. They didn't have to do that. That was a visionary view of the world. And if they hadn't done that, we wouldn't be having this conversation today.

So our hats need to go off for at least that amount of vision that DOD has shown in providing a civil capability.

Cooperation has been excellent. They have been with us on all of our international meetings. The U.S. Government's offer of use of GPS worldwide was facilitated, coordinated, and endorsed by the Defense Department. So while there are legitimate national security issues and legitimate issues of management, I want to make it clear that we think cooperation thus far has been great.

We are looking further downstream. At the possibility of, 5, 10, or 15 years from now, other enhancements to the GPS system satellites that we want to do jointly. There are certain R&D things you could do to even enhance the capability. We see them as being done jointly with DOD.

There are things about this differential capability where we could also make use of defense satellites. There are also activities for joint management of this activity that we are exploring, as the Secretary indicated. It is not beyond the realm of possibility that we could talk of even enhancing the capability of this GPS constellation with a couple of civil satellites.

If that happens, it needs to be done in a coordinated way. And we see that further enhancement as a real possibility.

Mr. GEREN. Well, as you know, these days with the defense budget, we are looking to develop dual use technologies and also looking at conversion opportunities. And it would seem that the opportunities presented by an expanded partnership in this area would fit very well into many of the themes that the Armed Services Committee, in the House anyway, is pushing. And I wondered if this wouldn't be something that perhaps the Armed Services Committee shouldn't also be briefed on with the hopes that we could facilitate further cooperation as we move forward with this?

Mr. POZESKY. I am sure both the FAA and the Defense Department would be happy to do that.

Let me also say that one of the things that the Secretary's task force is looking at is the issue of sustaining GPS capability in the long term. And that includes everything from long-term funding mechanisms to long-term management mechanisms. That is being addressed as part of the task force.

Mr. GEREN. It is sure exciting technology, and I think it is something that has tremendous potential for cooperation.

You mentioned long-term funding——

What sort of cost are we talking about looking down the road? And are there innovative financing ideas being considered outside of just the traditional or conventional government funding approaches?

Mr. POZESKY. The simple answer is, yes, there are innovative ideas. Let me answer the cost question first.

These GPS satellites are supposed to have an average life of around seven to seven-and-a-half years. They are actually lasting longer, but that is what the average life is supposed to be.

We believe that the replenishment of satellites and the maintenance is going to cost 250, maybe $300 million a year. While that is a substantial sum, I have got to tell you that, as compared to the cost we put into the ground systems that may ultimately be replaced by this technology, it is not a substantial sum. So there is significant cost benefit to be had.

We are talking, as I said, $50 million for a satellite launch, two to three—maybe 300 to $400 million a year for maintenance of the current GPS system.

There are lots of discussions going on about financing mechanisms, and I have personally had discussions that range as far as general fund revenues, to joint sharing in transportation trust funds and general funds, to corporate mechanisms for long-term funding of the GPS.

Mr. GEREN. You mean corporate private funding?

Mr. POZESKY. Yes, that kind.

Mr. GEREN. Public-private partnerships?

Mr. POZESKY. Yes. I don't think any of that is settled. But all of those concepts are being explored.

Mr. GEREN. I see the red light is on. I thank you for your testimony.

Mr. Chairman, thank you for having this hearing.

Mr. OBERSTAR. The gentleman from New York, Mr. Levy.

Mr. LEVY. Thank you, Mr. Chairman.

Good morning, Mr. Pozesky. I agree with the gentleman who said that the technology we are talking about is very exciting and I think very, very valuable. But I am led to believe, from something that I have read, and I am not even sure where, that GPS is subject to jamming. And I am wondering if you can comment on that.

And if that is true, what can be done in order to prevent someone from interfering with a system of that importance?

Mr. POZESKY. I need to start my answer by saying, yes, GPS is susceptible and could be susceptible to jamming. But I need to add, virtually any radio navigation system, such as VOR's and DNA's, are also subject to jamming. So that is a concern.

I need to also say, that, while it is a technical concern, it is not a safety concern because one of the things we are doing in our GPS design is putting in place what we call an integrity system, which will automatically alert the pilot if there is any problem with the GPS system. So if jamming were to occur, the pilot would get an indication of that and would know, therefore, to either go to a different satellite or not use the GPS system or use some other way to do that landing. So it is not a safety system.

We are looking into ways to increase GPS jamming protection. It does not, at the moment, look like casual, inadvertent jamming will be a problem. It looks like it would have to be very deliberate. We are doing tests. That is one of the hurdles we need to overcome that the Chairman mentioned. We need to really be able to rely on what we call a sole means system. We are moving to address that issue.

Mr. LEVY. If we go to a GPS system, do we maintain some sort of redundancy so if there is a problem, there is another system to fall back on?

Mr. POZESKY. That is clearly a possibility. Right now that is the way we are going to introduce GPS. We are not going to start phasing out anything. We are going to introduce it along with the other ground systems that we have. As we understand these issues better, the possibility really exists that we may elect to withdraw some of these other services from a cost benefit viewpoint. But we are not going to do that precipitously.

Mr. LEVY. The other issue I wanted to raise with you stems from the fact, when you send a satellite 11,000 miles into the air, what it generates is often available in the international community and not limited to those of us here in the United States.

To what extent is this technology being embraced in the international community?

And to those of us who are concerned with how we pay for these types of systems, is there some international option that we should be exploring?

Mr. POZESKY. Well, the answer to your first question is, to a great extent, we believe the international community will elect to take advantage of this technology because, as you have already observed, it is there; they can use it.

The Canadians, for example, are even more enthusiastic about the movement than we are, if you can believe that. And they are moving rapidly toward the implementation, as well as many other countries. In a continent like Africa where there are countries that don't have a lot of the ground infrastructure, GPS is a natural. So you will see this technology being used.

We have looked at the issue of how to pay for it, and that is one of the things that we are exploring. One of the characteristics of the system is that it is a broadcast system like a television system, and it only requires receivers to make use of it. So it is probably not practical to charge a direct user fee for the use of the GPS system.

Now, as we introduce these other differential capabilities, we talk about what we call value-added services. Those capabilities, for example, are going to be paid for probably locally, and I will give you an example. If the FAA were to field a differential ground network through its appropriation process, we would use F&E funds, that is also a user-based fund. So I would argue that although there is no direct user charge, there are user fees associated with those value-added services. That is the way I see this evolving.

Mr. LEVY. But this will strictly be a system that is built and paid for by the United States of America and probably will have benefits for the world?

Mr. POZESKY. At the moment, I would say, yes, that looks like where we are heading.

Now, there are fees that go into the trust fund for international operators. But, you know, the essential answer to your question is, yes.

Mr. LEVY. I see the red light. I thank you for your testimony.

I thank you, Mr. Chairman.

Mr. OBERSTAR. I would like to supplement what the gentleman was saying.

While the United States is offering this technology free and others are using it free, this technology is, like so much other technology that we offer through the FAA and through their certification process as the flying wedge. This opens the way for U.S.

commercial sales in many other technologies, and by continuing to be the world leader through this type of offering, we are opening the door for a whole range of other commercial opportunities for American technologies.

And eventually I think there probably will be some sort of a fee-based system, but that is far off in the future. I think we need to get this developed. The gentleman raised a very important point.

Mr. LEVY. I understand, and I don't oppose the system on that basis at all.

Mr. OBERSTAR. The gentleman was raising a very important point; and I thought, as a footnote, we ought to mention there are some tangible, as well as intangible, benefits that translate into big bucks.

Mr. LEVY. I am merely wondering aloud as to whether or not there are others benefiting where we ought to be thinking about their participation.

Mr. OBERSTAR. Let's get them hooked first, and then we will tax them.

Mr. Inhofe?

Mr. INHOFE. Thank you, Mr. Chairman. First of all, I apologize for not being here. This meeting coincided with an Investigation and Oversight Subcommittee meeting that we were having one floor up, and I am the Ranking Member on that subcommittee; so I had to be there. Upstairs we're talking about PFCs, so I am transitioning from the PFC to the GPS.

Let me, first of all, address something Mr. Levy mentioned. It is my understanding that there wouldn't be a way, even if it were desirable, to force a shutdown in certain areas or to certain others who may want to use it.

Is that correct?

Mr. BRODERICK. The best answer I can give to that is that anything is conceivable with modern technology, but you can't selectively shut it down for individual users.

U.S. international airlines are going to be counting on this system all over the world just like local, domestic airlines will. The best insurance that people have against something like that being done is that United or Delta or American or TWA would be equally as adversely affected as the local airlines. So it is not something that is a practical matter to worry about.

Mr. INHOFE. If the Chair will give me a little bit of latitude on time, since I didn't have an opportunity for an opening statement, I would like to start off with just a testimonial on the GPS system for, perhaps, some of my colleagues as well as maybe some of the people here.

A year—a little over a year ago, I flew a small airplane around the world. I had all kinds of navigation aids, but what I used was a Trimble TNL 780 and a Trimble TNL 3,000. At no point all the way around the world did we lose satellites where we were not able to use our GPS system. Going across the former Soviet Union, they have a rule that you have to use a Soviet navigator.

So I picked up a Soviet navigator. He didn't know GPS from PFC. He didn't know there was such a thing, and I can remember so well all they had had was NDB, which, of course, is a very inaccurate, ancient system of low frequency navigation. I can remember several times going into—under really low limits even though they didn't have published limits there, getting the coordinates of an airport in like Sovetskaya in northwestern Siberia and shooting an instrument approach. This guy was so impressed that we did NDB so well. It was with GPS all the time.

I think that we have a problem with this system. I am also on Armed Services, and I am trying to get some bare minimum navigation equipment on some of our heavy equipment that we are flying around. We actually have sextants hanging out of the ceiling and still are using NDB and some of the oldest of the VOR boxes.

But it is so cheap now, this unit that you have there, that flight mate. That is a garment, the one you are holding there. They essentially do the same thing. I have one of those flight mates on a small airplane. They now sell for $740. That unit can do almost everything. It doesn't have all the wave points that others have. I don't think it has intersections, but everything except intersections is in it for navigation purposes. And it is being used right now, and we need to expand the use of it.

The problem we have in government procurement is, by the time you make a decision whether or not you are going to buy something, you go in at those prices and then you are missing buying it at one-third the price when you get ready to do it.

Now, my question I have and my main interest in this is, what kind of progress are we making in using this as a certified approach system?

I know that you are working on it, and I know there are a lot of things that have been brought up in this hearing, even though I wasn't here to hear them, that are obstacles you must overcome. But I would kind of like to get a status report as to where we are at this time.

Mr. BRODERICK. Well, you are right; that is the sort of key to benefiting from GPS. We have, as you may be aware, implemented the overlay program in the United States which, in conjunction with a receiver that is certified to the technical standard order that we issued December 10th of last year, will enable you, with the database that will be available in a couple of months, to fly any nonprecision approach that is published in the United States.

Of course, you would need initial operational capabilities of the satellite system, too, to make that practically useful. But that is going to dovetail very nicely in a couple of months.

The precision approach capability that we are developing using these differential stations is something that is also coming along quite well. We had a very important meeting just a week ago out on the west coast to deal with the Minimum Aviation System Performance Standards which, when taken together with the TSO's from RTCA and the FAA orders, will enable you to fly special Category I approaches using a differential system privately purchased and privately used.

In other words, we will have to require whatever the technical folks determine is necessary in terms of training and charting and that kind of thing.

So we are pretty much ahead, as Marty said, of the power curve in terms of getting standards out before the hardware is out and available so we don't have a retrofit problem in providing standards and certification documentation that enables people to actually build this before the industry is ready. So we are pretty pleased with the way things are going.

Mr. INHOFE. You know, sometimes it takes a little longer to get through these things, and it is much more complicated than the public perceives. And I try to explain that.

I remember when you are going through your MLS system—and I am now, in retrospect, glad that it took so long because I didn't think it was a very good system, and it required such an investment not just for general aviation for the airlines that this does not require. We are talking about stuff you can get in there and is real cheap, has incredible accuracy and has an application that it just blows your mind when you think about what all is out there.

So I would like to make the request to be kept up to date particularly as far as your progress is concerned on precision approaches because I have a lot of people who make inquiries, and I appreciate the fact that the Chairman is having this hearing today so that we can call this to the attention of not just those of us here in Congress but to the general public.

Mr. POZESKY. Thank you, sir.

Mr. OBERSTAR. Mr. Geren, further questions?

Mr. GEREN. No, Mr. Chairman.

Mr. OBERSTAR. Mr. Pozesky, one of the questions raised about the FAA's management of this system is that there may be overlaps, there may be conflicting areas of responsibilities within the agency, yet you have described the Satellite Operation Implementation Team, SOIT—however you are pronouncing that.

Mr. POZESKY. We call it SOIT, sir.

Mr. OBERSTAR. All right, whatever. And is it the RTCA, the outside group that is coordinating?

Is something else needed? You say you have developed a technical service order that defines the minimum operating performance standards. Have you really taken a look at the way FAA is proceeding to make sure you really have streamlined this whole process so that it could move ahead as quickly as possible?

Mr. POZESKY. Mr. Chairman, I personally have become very aware in just the last week that, indeed, something else is needed. And what is needed is a really crisp way to communicate to the community what we are doing because I am sure you will hear in the course of these hearings that there are people who are uncertain or confused about where we are going.

It is not because we don't have a story. It is because we haven't communicated it as well as we need to communicate it. And Tony and I just were talking recently about the need to come up with a mechanism to get this communication flowing throughout the community so that everyone knows what is going on.

Again, this technology and this program are moving literally like wild fire. And I think it has kind of overwhelmed us. So we are aware of the need to do a more comprehensive job of communicating what is going on in the FAA, where we are headed, and what our time scale is, et cetera, et cetera. That clearly is needed. And at this point, I can just take an IOU and give you a commitment that we are going to do our best to get that communication flowing as well as we can.

We also think that internally managing the program through this SOIT application really is important to stay with because that really involves the people who actually have to do the work. And it really empowers the senior division technical folks in the FAA, and it enables them to work through the organization moving rapidly.

There has been talk about taking that off-line and coming up with this special effort. We are worried about that special effort as to whether or not it winds up being a problem. We really think it is necessary to keep people and flight standards and aircraft, in R&D, involved, the people who are going to make this happen every day of the week involved and coordinated.

So we have this SOIT. It involves all the relevant parts of the agency. They meet regularly. Tony, I, and Bill Pollard jointly chair that activity. We meet with them regularly, and it is kind of a coordination management mechanism, a kind of an empowered team to use a TQM, total quality management approach. And it has worked well for us.

Mr. OBERSTAR. Are you involving air traffic controllers and airline flight dispatchers, the people who are really on the firing line, on this process?

Mr. BRODERICK. We haven't yet gotten to the dispatchers, although we have extensive involvement of air traffic controllers.

As I indicated earlier, we are actually having the air traffic controllers sit with the flight standards people so that they can exchange information in a real-time basis and work on developing these procedures.

Mr. OBERSTAR. Okay. Well, I think that is very important to have the folks who are on the firing line involved in this process so later on you don't come up with—come up against some concerns that they have that might usefully have been raised earlier.

I have a concern also on safety side, reliability. One of the things FAA has been extremely good at doing is building or requiring the building of redundancy into all systems recognizing that five, six, seven miles in the air there is little margin for error. You can't pull over to the curb and fix it.

And there is—in all the other technology, there is a redundancy that if something fails, people know that it has failed almost instantaneously. But from what I have read of the literature and progress of this technology, that it may—GPS may not let people know that there is a fault in the system for as much as an hour from the time the fault occurs.

How do you address that?

Mr. BRODERICK. That is an excellent question. The GPS satellite system, as currently designed, does have that drawback.

One of the things people are looking at is incorporating the satellite health monitor at the ground stations and broadcasting the health of the satellites to the people that are using the signal.

But in an attempt to short circuit that and really implement things early, what we did when we designed our standards for aviation use of GPS receivers is to be approved for Instrument Flight Rules navigation is require Receiver Autonomous Integrity Monitoring.

In other words, the receiver has built into the computer—and it is not in this one because this is not a TSO certified unit, but it would have one if it were its own satellite checking system. So what you do is you look, check the satellite signals one against the other, using extra satellites.

Therefore, to do that—and if anything goes wrong, either by jamming or by a satellite giving a signal which doesn't agree with the position computed from the other satellites—a flag goes up, and it tells the pilot that he or she may not use that signal for navigation. And it is getting a system that has availability of that integrity all the time that is causing us to look at things like ground augmentation and extra satellites that we talked about just before the hearing.

But right now, from a safety viewpoint, we have considered the problem that you have noticed in the system and designed, into the requirements for aviation use, a computer system which automatically detects problems with the satellite and, essentially, immediately notifies the pilot.

Mr. OBERSTAR. Very good.

What is the probability that the satellite-based technology will be able to provide precision approach capability?

Mr. POZESKY. Very high. I think that it is almost a virtual certainty that we can provide Category I capability. We have already demonstrated that. There are airlines that are planning to use it already.

I think we have very optimistic people. We are working with the best universities in the country—Stanford University, for example.

Frankly, and candidly, I started off as a pessimist in this area; and I am getting more optimistic as every day goes by. But I need to tell you that we haven't yet been able to pull that off regularly in anything but the most finely tuned environment.

I was asked a question about probability. I think we wound up putting a number of about 70 or 80 percent on it, before the debate was over, in terms of probability.

But for Category I, I think it is virtually a done deal.

Mr. OBERSTAR. Well, there are other questions I might want to raise. I will defer to Mr. Clinger at this point.

Mr. CLINGER. Mr. Chairman, I just have some other questions that I would like to have submitted for answer in writing.

Mr. OBERSTAR. Without objection, so ordered.

[The questions submitted to FAA by Representative Clinger and responses, follows:]

U.S. Department
of Transportation

**Federal Aviation
Administration**

Office of the Administrator

800 Independence Ave., S.W.
Washington, D.C. 20591

OCT 25 1993

The Honorable William F. Clinger, Jr.
Committee on Public Works and
Transportation
Subcommittee on Aviation
House of Representatives
Washington, DC 20515

Dear Congressman Clinger:

Thank you for your interest in the Federal Aviation Administration's plan for implementing Global Positioning System technology into the National Airspace System. Please refer to the enclosed document for the answers to your specific questions.

If you have any further questions or need any additional information, please contact me at any time.

Sincerely,

David Hinson

David R. Hinson
Administrator

Enclosure

QUESTIONS FOR DOT ON SATELLITES OR THE GLOBAL POSITIONING SYSTEM (GPS)

En Route

All questions below assume GPS can be used for en route navigation and that existing traffic separation and navigation ground equipment will be decommissioned. If this is contrary to FAA's current thinking, please explain.

1. Please specify in detail what equipment would no longer be necessary if GPS could replace the en route radar system. What en route navigation equipment would still be necessary with GPS?

> The FAA has reached the decision to deactivate all of its older long-range primary radars. This move, which is not related to the availability of GPS technology, will save the expenditure of $1.4 billion. We plan to continue to use the secondary surveillance radar (beacon) system, eventually transitioning to a GPS-based system. In order for a GPS-based automatic dependent surveillance (ADS) system to work, all aircraft would have to be equipped with ADS equipment. Appropriate safety studies will need to be performed to determine how soon we can support a decision to base all navigation and surveillance on one type of equipment. None of the FAA operated en route navigation aids (VHF omnidirectional range, distance measuring equipment and nondirectional radio beacon) would be needed after all users are equipped with GPS.

2. What is the annual maintenance cost for the current en route radar system (do not include maintenance cost of equipment that would still be necessary with GPS)?

En Route Surveillance System (radar):	
Primary long-range radars	$35M
Secondary (beacon) radars	$15M

> Note: All costs are in 1993 dollars and are rough order-of-magnitude estimates.

3. What capital costs would be saved if GPS replaces the current en route radar system?

If our analysis shows that we can transition directly to GPS without having to replace our current aging en route beacon system, the savings estimate is as follows:

En Route Surveillance System (radar):	
Secondary (beacon) radars	$0.7B

Note: All savings are in 1993 dollars and are rough order-of-magnitude estimates.

4. How much would commercial and GA aircraft have to spend on equipment for GPS en route navigation? How much do they spend on today's equipment that would be replaced with GPS?

Navigation	**GPS**	**Today's Equipment:**
Type aircraft	**Per aircraft/total**	**Per aircraft/total**
Commercial	$64K/$400M	$110K/$700M
GA	$3K/$360M	$20K/$2.4B

Note: All costs are in 1993 dollars and are rough order-of-magnitude estimates.

5. What type of equipment would be necessary to interface data from GPS to the air traffic control equipment for en route navigation? How much would this cost?

The GPS-based surveillance system would require equipment for user aircraft and the ground-based air traffic control (ATC) system. Airborne users will require a transponder to transmit position data to the ground segment. Equipment modifications for aircraft would be relatively minor to use a GPS-based ATC system.

Surveillance	GPS	Today's Equipment:
Type aircraft	Per aircraft/total	Per aircraft/total
Commercial	$5K/$30M*	$25K/$15M
GA	$4K/$500M*	$1.3K/$160M

Notes: All costs are in 1993 dollars and are rough order-of-magnitude estimates.

* GPS navigation technology advancements could lower this estimate significantly, depending on the eventual system architecture.

The ground segment will require equipment to receive the aircraft position data and process it for use in the ATC system. An initial estimate for this equipment is $325 million (1993 dollars).

Precision Landing

It is assumed the costs provided for the questions below are for one ILS, MLS, or GPS system (assuming GPS uses a local area differential monitor). It is also assumed one GPS system will provide precision landing for an entire airport while the ILS or MLS system will provide precision landing capability for only one end of one runway. Please comment if these assumptions are incorrect.

The instrument landing system (ILS) provides precision landing capability only to the runway end for which it is installed. Although microwave landing system (MLS) is normally installed to serve a particular runway, the coverage area of MLS could, in some situations, also provide some precision landing capability to other runways within that coverage area. The achievement of precision approach capability with wide area differential GPS (WADGPS) is anticipated to provide precision landing capability to all airports within a large geographical area. The WADGPS concept we are exploring requires installation of a limited number of ground stations and the use of geostationary satellites in addition to the constellation of GPS satellites. It is anticipated that local area differential GPS will be used primarily for Cat II/III precision approaches; however, the technical feasibility of this concept is still in the development stage.

6. How much will it cost to develop multiple approach paths for MLS and GPS? Will it be more expensive or more difficult with one system over another?

It should cost about the same to develop and test approach procedures regardless of the type of navigational aid used for the approach; roughly $20,000 per approach path.

With GPS, the desired approach path is constructed by the aircraft avionics. GPS permits any number of approach paths to be defined for any runway. Since this capability is the normal operating mode of GPS, there is no additional cost associated with having multiple approach paths for any runway, other than the development of the procedure itself. MLS advanced procedures such as curved, segmented, or offset approaches would employ the same technique for constructing approach paths within the coverage area. The standard MLS ground equipment is designed to accommodate this feature. However, avionics required to perform the advanced approach procedures would be more complex and costly than is necessary to perform straight-in approaches.

7. How much does it cost to purchase and install an ILS system (Cat I, II, and IIIa, b, & c) -- do not include equipment that would also be necessary for an MLS or GPS system? How much will it cost to purchase and install a GPS precision system (Cat I, II and IIIa, b, & c)? How much will it cost to purchase and install an MLS precision system (Cat I, II and IIIa, b, & c)?

System	**Cat I**	**Cat II**	**Cat IIIa**	**IIIb**	**IIIc**
ILS	$0.8M	$1.1M	$1.3M	$1.3M	$1.3M
MLS	$1.0M	NA	$1.1M	$1.1M	$1.1M
GPS	$(0.06 - 0.2M)*	**	**	**	**

Notes: All costs are in 1993 dollars, based on 800 ILS runway ends, and are rough order-of-magnitude estimates. Costs do not include approach lighting or runway visual range (RVR).

* Cat I GPS approaches are expected to be available with WADGPS. Cost per runway end is expected to be approximately $200,000 based on 800 ILS-equipped runways. A conservative estimate of 3,000 runways would qualify for GPS approaches; cost per runway would be about $57,000.

** Cat II/III GPS feasibility is still in the research and development stage. No reasonable cost estimates can be developed until some determination is made as to what will be required to provide Cat II/III GPS approaches.

8. What additional equipment is necessary for an ILS, MLS, or GPS precision landing system (such as RVRs or approach lights) and how much does it cost (Cat I, II and IIIa, b, & c)?

Equipment	**Cat I Cost**	**Cat II/III Cost**
Medium-Intensity Approach Lighting System RAIL (MALSR) (Cat I lighting)	$0.8M	NA
High-Intensity Approach Light System (ALSF) (Cat II,III lighting)	NA	$2.6M
RVR	**	$0.2M*
ILS Marker Beacons	$0.1M***	$0.1M***

Notes: All costs are in 1993 dollars and are rough order-of-magnitude estimates.

* Includes a three RVR system.

** An RVR is not usually required for a Cat I approach but may be justified on a case-by-case basis.

*** Not required for MLS or GPS.

9. How much does it cost to maintain an ILS, an MLS, and a GPS precision landing system? Does it differ for Cat I, II, and IIIa, b, & c?

System	Cat I	Cat II	Cat III
ILS	$80K	$100K	$100K
MLS	$70K	$80K	$80K
GPS	*	**	**

Notes: All costs are per year (in 1993 dollars), based on 800 ILS runway ends, and are rough order-of-magnitude estimates.

Costs do not include maintenance for approach lighting and RVR maintenance.

* Cat I GPS approaches are expected to be available with WADGPS. Cost per runway end is expected to be approximately $50,000 based on 800 ILS-equipped runways. Conservative estimates indicate that at least 3,000 runway ends would qualify for GPS approaches; cost per runway would be about $10,000.

** Cat II/III GPS feasibility is still in the research and development stage. No reasonable cost estimates can be developed until some determination is made as to what will be required to provide Cat II/III GPS approaches.

In addition to equipment maintenance costs for precision approaches, approach lighting and RVR maintenance costs are also required to support this particular type of approach.

Lighting or RVR	Approach Type	Cost
MALSF	Cat I	$25K
ALSF	Cat II/III	$60K
RVR	Cat I/II/III	$15K

Note: All costs are per year (in 1993 dollars), based on 800 ILS runway ends, and are rough order-of-magnitude estimates.

10. What is the cost for the equipment needed in the aircraft for ILS, MLS and GPS for commercial aircraft and GA aircraft? Is there a major cost difference between Cat II and Cat IIIa, b, and c?

System ***	Cat I Per aircraft/total	Cat II Per aircraft/total	Cat III Per aircraft/total
ILS: Commercial	$40K/$240M	$70K/$420M	$140K/$840M
ILS: GA	$2K/$200M	NA	NA
MLS: Commercial	$55K/$330M	$140K/$840M	$150K/$900M
MLS: GA	$7K/$700M	NA	NA
GPS: Commercial	$31K/$190M*	**	**
GPS: GA	$3K/$300M*	NA	NA

Notes: All costs are in 1993 dollars and are rough order-of-magnitude estimates.

Costs for regional airlines are combined with commercial air carrier costs.

* Cat I GPS approaches are expected to be available with WADGPS. GPS without any differential capability would be suitable only for nonprecision approaches.

** Cat II/III GPS feasibility is still in the research and development stage. No reasonable cost estimates can be developed until some determination is made as to what will be required to provide Cat II/III GPS approaches.

*** The major cost difference between Cat II and III avionics is for equipment redundancy. Cat III ILS costs also include radar altimeters.

GPS System

11. GPS consists of 21 satellites and 3 back-up satellites. Does FAA expect that additional satellites are needed? If so, will FAA pay for the additional satellites? What would be the estimated cost to purchase and launch another satellite?

The FAA has determined that additional satellites are needed. The options include using the Global Navigation Satellite System (GLONASS), geostationary satellites, or more GPS satellites. While FAA considers GLONASS a viable option (and lowest cost in the near term as long as the service is free), the risk of relying on this capability is considered high. The geostationary option is preferred for use in U.S. airspace because of its reliability and low overall cost. Four INMARSAT-3 satellites containing GPS-like navigation payloads will be launched in 1995 and in service in 1996. We prefer to piggyback payloads on planned geostationary communications satellites for several reasons. First, it reduces launching costs by combining navigation and communication payloads on existing launch schedules for communications satellites. Second, the coverage of a geostationary satellite is equivalent to at least three additional inclined-orbit GPS satellites, and aviation needs geostationary satellites for GPS integrity broadcast. INMARSAT has quoted an approximate cost of $2.5 million per year for lease of each geostationary GPS-transponder. This is much more economical than the Department of Defense (DOD) estimated cost of $100 million to build and launch a GPS satellite.

12. FAA has free access to GPS until 2003. After 2003 FAA may have to assume some of the costs. How much will it cost annually to maintain GPS (satellites and ground equipment and facilities) after 2003? How much of that cost will be paid by FAA?

The basic GPS signal (100 meters, 2drms, 95 percent probability) will be available to users worldwide indefinitely with at least a 6-year notification of any decision by DOD to discontinue the service. The annual cost to operate and maintain the full GPS constellation is approximately $400 million. This includes maintenance of the ground monitoring network and replenishment satellites. Currently, the DOT/DOD Task Force, is addressing institutional issues such as joint control and funding of GPS, among others. The report of its deliberations is due to the Secretaries of Transportation and Defense in November of this year at which time a clearer picture of FAA's role in the management/funding of GPS should be available.

13. What is the schedule and cost for certifying GPS for en route and precision landing? How does this compare to the timing of the MLS? When does FAA expect commercial aircraft to be equipped with GPS avionics? When would the ground based ILS and en route navigation systems be decommissioned?

GPS avionics have already been approved for supplemental use to fly in oceanic, domestic en route, terminal, and nonprecision approach phases of flight. Approval of GPS as a sole means to support these same phases of flight is scheduled for fiscal year 2000 in conjunction with implementation of the GPS integrity broadcast (GIB) system. The approximate cost to field the GIB system will be $100 million. Cat I precision approaches are expected to be supported by the WADGPS now being evaluated at the FAA Technical Center. If this technology is proven and implemented, Cat I precision approaches using WADGPS could be certified for supplemental use by the year 2000 and sole means by 2005. The cost will be $60 million to upgrade the GIB system to include the wide area differential correction message and provide additional GPS-like ranging signals from the communication satellites. Precision approaches to Cat II/III will be achieved by local area GPS techniques. Feasibility demonstrations to prove GPS local area capability to Cat III specifications are scheduled for completion by mid-1995. This timing coincides with the full-production decision point on MLS. The FAA expects Technical Standard Order-certified GPS avionics to be available by the fall of this year to support supplemental use of GPS for all phases of flight down to nonprecision approach. Decommissioning of existing en route and nonprecision navigational aids could begin as early as 2002. Decommissioning of ILS in favor of GPS would not begin until well after 2005 due to present research and development schedules.

14. If GPS provides navigation and communication services to the world aviation industry, is there any way a fee could be charged to recoup the cost of the United States after the year 2003?

GPS as currently configured provides navigation, not communication services. The U.S. position, as stated at the International Civil Aviation Organization Tenth Air Navigation Conference, is that GPS standard positioning service (SPS) will be provided on a continuous worldwide basis, free of charge, for 10 years (beginning 1993). Additionally, the United States further clarified its offer for GPS-SPS service to extend into the foreseeable future.

To address concerns about cancellation or degradation to the service, the United States intends to provide a minimum of 6 years advance notice of termination of GPS or elimination of GPS-SPS.

Any future augmentations to GPS-SPS services may or may not have user fees associated based on future requirements. The FAA plans to pay for the proposed augmentations with available trust fund or other resources in the same manner as the existing navigation and surveillance systems are procured and maintained.

Mr. OBERSTAR. I want to observe, though, that to wait for the Europeans or others to develop a navigational system so that we have one system that is uniform and applies to everybody is the tail wagging the dog. If they aren't ready, let's not wait for them. Let's move ahead. We have got the technology.

This is an area where the United States has preeminence. And, you know, I heard five years ago European authorities saying we are going to develop the super, above-all, fastest ever security detection. It is still on the drawing boards.

Four years ago, I heard the Europeans in Munich at an airport operators conference say we are going to develop a modern air traffic control communications system like you have in the United States. They haven't even got bids out on it. You know, let's not wait for them.

Less than half of all intercity paid transportation in Europe is by air; less than half. More than half of all intercity paid transportation in America is by air. We have much more at stake, a much bigger stake worldwide in this. And we ought not to wait for them and don't let those international organizations, they will fiddle around on "principle." We can discuss these things on "principle" until we are dead in the air.

Mr. POZESKY. Mr. Chairman, your endorsement of that strategy is essential, and that is where we are headed.

Mr. OBERSTAR. Thank you. All right. I appreciate your presentation here and the supporting technology. That has been a fascinating display in this room today.

We will proceed to our next witness. Mr. Robert Ferguson, President of Continental Airlines and a user of the technology.

Before Mr. Ferguson takes his seat, the Chair would like to observe the presence today of the former FAA Administrator, Don Engen, who, in his tenure, stimulated and encouraged the development of the technology we are discussing today.

Good to have you with us, Mr. Engen, Mr. Administrator, and to see you continuing your interest in aviation.

The Chair will note for the record the presentation of several black boxes on the table that will accompany Mr. Ferguson's testimony.

We expect those to be explained.

TESTIMONY OF ROBERT FERGUSON, PRESIDENT, CONTINENTAL AIRLINES

Mr. FERGUSON. Carefully brought in through security.

Good afternoon, Mr. Chairman. Thank you for disrupting your lunch hour to accommodate my schedule. My name is Robert Ferguson. I am the President of Continental Airlines, Chief Executive Officer as well. I am pleased to be able to testify before this subcommittee on an issue of great interest to the aviation community at large and to me personally, as a user of GPS for the better part of two years.

With your permission, I would like to make a brief oral statement and ask that my full remarks be included in the record of your committee.

Before I move on to more technical aspects of my testimony, I would also like to commend the National Commission To Ensure a Strong Competitive Airline Industry and specifically Commissioner Barclay whose system capacity team thoroughly addressed the Global Positioning System and have recommended that the air traffic control system in the U.S. change to satellite-based navigation and that the FAA and the airline industry accelerate the implementation of GPS through the public and private consortium.

Mr. Chairman, I am pleased to report to this committee that Continental Airlines is already in the process of equipping some of our aircraft fleet with GPS navigation for use en route and terminal procedures. This fall, we will become the first airline using GPS-based approaches. We are also evaluating a number of manufacturers and will decide over the next two weeks which will become our supplier for future GPS products. That installation will also commence prior to year end. That installation will replace Omega and similar systems and will pay itself back in a mere 91 days.

Why is Continental so committed to GPS? Because we believe that these satellites provide a number of unique opportunities to aviation. We are on the threshold of redefining the entire manner in which we conduct aviation worldwide. Through the use of satellite system and various communications systems, it is now possible to safely navigate anywhere in or on the world and around the Earth with absolute certainty as to speed, direction, altitude, time, and collision avoidance.

Implementation of GPS will allow us to communicate through voice and data transmissions virtually worldwide, navigate accurately and reliably anywhere in the world without even adding one more ground-based system and track precisely all aircraft and other aviation-related vehicles anywhere in the world.

Each of these elements is discussed at greater length in my written testimony. For now I would like to address the issue of implementation.

Satellite-based communication navigational controlling systems will improve the safety and efficiency of our air transportation system and save the industry $5 billion annually through delay reduction and direct routing.

The U.S. airline industry simply cannot afford for the implementation of GPS to be bogged down in bureaucratic red tape. Frankly, it is not important whether we utilize NAVSTAR GPS, GLONASS, or INMARSAT as the provider of the world satellite signal.

Since the United States represents approximately 45 percent of the aviation traffic in the world, we should focus on the continental U.S., implement a system using GPS which is already in place, and gradually expand that system throughout the western hemisphere and eventually to Europe and the balance of the world if they so choose.

On the issue of costs, we believe the expected benefits of a fully implemented system will justify the investment. However, there is a need to provide airlines with an early benefit to offset these costs. An optimistic scenario for global implementation is that this will take about 14 years from the time the need is identified to the time the system is fully operational.

In this time, interest alone will amount to three dollars for every dollar invested. Therefore, if early benefits are not achieved, the accumulated interest may outgrow the projected operational benefits. We also believe there is a need to question traditional assumptions and procedures within the FAA in an effort to shorten the implementation time.

It is clearly unacceptable to delay implementation of the new era because of parochialism. A top-down audit should be accomplished of FAA personnel, budget, and assignments to eliminate overlapping of conflicting areas of responsibilities regarding satellite-based aviation; and the FAA's focus should be maintained on ensuring earliest possible benefits.

Mr. Chairman, before I conclude my oral statement, I would like to mention five recommendations which I included in my written testimony to the subcommittee to consider.

First, establish a centralized authority within the FAA to oversee the earliest benefits possible for the users of this system, the airlines.

Support a progressive approach to acquisition such as the use of a consortium.

Establish GPS-based precision approach criteria and an implementation plan that will eliminate any requirements to equip aircraft with MLS systems.

Fourth, accelerate the selection of vendors, including sole sourcing if it will accelerate implementation.

Mandate implementation of the program domestically while moving negotiations with the other countries to a "fast track."

Finally, Mr. Chairman, before I answer the questions of you and your colleagues, I would like to ask you to look at the equipment that I have brought with me today.

The tower to the left represents the equipment on a 727 appropriately equipped for long-range navigation. That equipment by itself costs $204,000 at today's prices.

To my left on the table is the necessary GPS equipment to reproduce every function that is performed in that category and has a total cost of $57,000 and has not been mass produced yet.

Obviously there are vast cost savings available.

Mr. Chairman, I appreciate the opportunity to appear before your committee. I would be happy to answer any questions you might have.

Mr. OBERSTAR. Well, that latter is certainly a very impressive demonstration of confidence in and value of the system and especially to those of you who are on the operational front, if you will, the frontline of aviation. And I particularly want to call attention to page 5 in your testimony in which you back up your support for GPS with specific dollar savings that industry expects to achieve.

And I wanted to ask whether those numbers are based on your experience so far and then projected out into those global numbers that you used?

Mr. FERGUSON. They are based on our experience, particularly the en route savings are quite obvious.

In addition, the landing functions are based on experience. As one of your commission members mentioned earlier about using GPS, we differentially equipped—GPS differentially equipped Intercontinental Airport about three months ago.

We carried the unit to the roof of our building and plugged it in with an extension cord and executed precision approaches immediately there after. Savings from simply missed approaches are directly calculable. We can calculate that with exact precision. We do believe the savings indicated are very documentable, and they are documentable by objective fact.

We did not include savings to the United States Government from abandonment of existing systems, from personnel reductions, from other things that are possible.

Mr. OBERSTAR. The FAA has developed a master plan for satellite technology with setting forth specific time frames by which to measure action and milestones by which to judge progress.

Have you reviewed this plan? Do you have some observations to make upon it or anything you might disagree with?

Which elements do you think might be accelerated, harking back to testimony of Mr. Broderick and Mr. Pozesky who the latter said he thought there were ways in which they could do things faster and better?

Mr. FERGUSON. I think that they are fairly correct in their statement that the FAA is, today, with respect to this technology, ahead of where it has been ever before. That is interesting. That is curious.

But as you pointed out in your opening statement, it was 1982 when this technology was first surfaced. It is now 1993, 11 years later. The system will be up and fully operational this fall. The technology has been available for many years to make these systems functional in the area of surveying alone as mentioned by the Secretary this morning. These systems have been accepted for many years as being more accurate than the traditional methodologies and, in fact, were hugely cost beneficial, reducing the cost of an initial survey from $10,000 to $400.

In my view, the system should be up and operational now. In my view, total quality management is not the issue here. The more interesting issue is corporate reengineering which is the sort of next step of quality management, and what it says is you ought to leapfrog the existing process. There is no need for intermediate TCAS in my view. We ought to move directly to TCAS IV if that is what they wish to call it. We ought to find systems that allow us to implement the highest degree of safety and the most economic environment as quickly as possible. And if that means shelving some intermediate systems, so be it.

Mr. OBERSTAR. You are looking for leapfrog technology, as I call it, to jump over things that may be interim and move dramatically ahead, and you encourage that.

Mr. FERGUSON. There is no reason why we can't do it. This particular one, as the FAA pointed out, is on the shelf. It has been on the shelf. It is time to get about and get it done. And the five-year time arising, to the end, ought to be more than adequate.

Mr. OBERSTAR. Thank you.

Mr. Clinger.

Mr. CLINGER. Thank you, Mr. Chairman.

Mr. Ferguson, thank you for participating in this hearing about what really is one of the most exciting prospects I think we have had for commercial aviation in a long, long time.

Obviously the reason you and I presume most of the airlines are supportive of this is because of the savings that enables you to realize, and it certainly couldn't come at a better time.

Mr. FERGUSON. We could use a little help.

Mr. CLINGER. Would your support of the GPS change if FAA had to pay to operate and maintain it? There is now, under the present proposal, DOD proposing to launch three to four satellites a year, about $250 million annually. But if that arrangement were somehow not survived, would that change your view?

Mr. FERGUSON. First, I would make the following observation to the extent that the DOD satellites have proprietary service, that is they render to the Department of Defense, they obviously should pay for those.

With respect to the balance of the costs, if the savings that we anticipate can be realized, I think the industry would be prepared to pay for the satellites. It simply is a cost-benefit opportunity, and it is just overly obvious that it works. And we should just get about doing it.

The cost is not going to be the core issue, assuming that we implement this thing properly so as to get the savings in the beginning somehow contemporaneous with the investment. This is the one case in aviation that I have seen in 18 years where there is an opportunity to get the savings contemporaneous with the investment.

Mr. CLINGER. So you would see that the industry would be willing to invest in this because of savings?

Mr. FERGUSON. Absolutely. Particularly if we can simultaneously—and the FAA is right—clean up the system. There are vast savings in there.

Mr. CLINGER. You mentioned the need for the FAA to establish a public-private consortium to expeditiously implement, develop and implement the system.

What advantage do you think that has over the present existing FAA procedures for development and implementation of these systems?

What additional benefits do we get from that sort of a consortium?

Mr. FERGUSON. Principally, I believe the benefit that you get is that industry—and I am really talking about the airlines here—want these systems up and operational, and they want them up and operational as quickly as possible.

The FAA's role is an issue of safety and making sure that we do things properly. The industry, I believe, is ready to push this technology through to conclusion very quickly. It doesn't matter whether the vendor is one or two.

The FAA, at the moment—and I am not being critical here—they are following standard procedures, and they are perfectly fine—but is interested in how you integrate one piece of equipment with another. It doesn't matter. Pick one. Any one. And go with that one. That is all we need to do. We don't need to study.

There are six different kinds of communications. I am not a communications expert, but industry experts, who I would put great trust in, like Boeing as an example, would tell you of the six types, three will work, three won't; and it doesn't matter which of the three you pick; just pick one; and let's get about doing it; it doesn't matter.

Mr. CLINGER. This broader question of what I view as the necessity to have a capable international system, I think that will vary internationally.

Would you agree that we really need to be working within the ICAO system to try to get a system so that you don't have to carry a whole bunch more boxes in your planes?

Mr. FERGUSON. We would absolutely encourage a coordinated system, and we think that makes good sense.

But I think the reality is that what you are talking about is a system that is 10 or 15 or 20 years off.

What we are saying is it is here; it is now. We are in the U.S.; and it is 45 percent of the world's aviation. There are probably 200 to 250 airplanes in the United States airline fleet that each visit foreign countries in terms of the major transoceanic services. They may have to be equipped with multiple systems. But for the balance of the fleet, we are not ever going to send a 737 to London. It doesn't need an MLS system if it goes to England.

What we need is a quality system in the U.S., and we need it quickly. And, you know, if we are on a program for five years and satellites have an eight-year average life, as was testified, we only get a three-year pay back. It is time to get it done.

Mr. CLINGER. Thank you.

Mr. OBERSTAR. Mr. Geren.

Mr. GEREN. I have no questions. But I would like to welcome Mr. Ferguson to the panel. The new Continental has a strong Fort Worth connection, and I want to wish him the best. I am particularly interested in hearing the practical applications of a lot of this technology and excited about its usefulness as we move into the future.

I thank you for your testimony.

Mr. FERGUSON. Thank you, Congressman. I appreciate it.

Mr. OBERSTAR. One of the consumer complaints that we hear is that airlines are not serving with jet capability smaller-sized communities.

Airlines respond, well, it is a lack of navigation and landing aid equipment.

Will technology offered through GPS make it possible for airlines to serve more communities, smaller-sized communities, with larger equipment?

Mr. FERGUSON. The answer to that is, yes, it will make it possible.

Mr. OBERSTAR. Where the market justifies it? Where the passenger traffic justifies it?

Mr. FERGUSON. But you are going to have to have some passengers. You can't go to Paris, Texas, just to pick a place in Mr. Geren's district. But you can go to many other locations. And 4400 places in the U.S. will become Category I compatible with fairly limited investment.

And that is quite a radical change from where we are today.

Mr. OBERSTAR. There are some aspects of the technology that do need to be proved out. And the Differential GPS, for example, do collect data coming from the satellite and transmits that data to incoming aircraft. That is an important part of that.

One of the questions before the FAA and the DOD and airports and airlines is, should there be Differential GPS at every airport? Or should you move to a technology that has maybe 20 or 30 of these systems spread throughout the United States strategically located?

What is your view and experience? What concerns would you have about that matter?

Mr. FERGUSON. Our view is, in essence, 20 to 30 is about what is required in order to provide the precision in air operation, which is to say not in proximity to the ground.

You, nevertheless, are probably ultimately going to want to have a local differential compensator that provides additional correction, certainly at the major airports so as to advance your capability.

And the FAA is quite right, in order to get the Category II and Category III, you need highly repeatable and very reliable systems. And at least to date, our technical people believe that requires the installation of a local differential units.

The particular one that we installed in Houston, for a short test, cost $17,000 at today's prices. I challenge you to compare that to an ILS at 1.2 million, or thereabouts, for a single runway.

Mr. OBERSTAR. So far as that cost could come down, that is a doable concept. And you may want to consider the DGPS only at congested airports or the most highly vulnerable airports.

Probably not every airport in America needs one?

Mr. FERGUSON. They probably do not.

Mr. OBERSTAR. I want to thank you for being a participant early on in the development of this technology and for your enthusiasm for it and for the very solid suggestions you have made about moving it ahead more speedily.

I assure you that we will have the full industry—and the FAA will have the support of this committee—in pressing onward to get this up and operating as quickly as possible so the benefits can be achieved for aviation.

Mr. FERGUSON. Thank you. I appreciate it.

Mr. OBERSTAR. Thank you very much.

The committee will recess for this vote and then resume in approximately one hour—quarter to 2:00—for the balance of our testimony today.

[Recess 12:50 p.m. To 2:15 p.m.]

Mr. OBERSTAR. The subcommittee on aviation will resume its sitting. And apologies for the intervening votes and other unforeseen scheduling delays.

TESTIMONY OF DAVID WATROUS, PRESIDENT, RADIO TECHNICAL COMMISSION ON AERONAUTICS; STEVEN J. BROWN, VICE PRESIDENT, AIRCRAFT OWNERS & PILOTS ASSOCIATION; ROGER FLEMING, VICE PRESIDENT, AIR TRANSPORT ASSOCIATION; SEIGBERT PORITZKY, SENIOR VICE PRESIDENT-TECHNICAL AFFAIRS, AIRPORT COUNCIL INTERNATIONAL NORTH AMERICA; JOHN O'BRIEN, DIRECTOR, ENGINEERING AT AIR SAFETY DEPARTMENT, AIR LINE PILOTS ASSOCIATION; JOHN M. BEUKERS, BEUKERS TECHNOLOGIES; AND DAVID HAAPALA, DIRECTOR, FLIGHT OPERATIONS DEVELOPMENT, NORTHWEST AIRLINES

Mr. OBERSTAR. And our next panel is already seated. I will not call them by name but in order of presentation.

Mr. Beukers of Beukers Technologies, by the luck of the draw, you are first—or by common agreement, you are first.

And I will ask each witness, in turn, to identify themselves and their organization.

Please proceed.

Mr. BEUKERS. My name is John Beukers. I am an independent consultant engaged in matters concerning the implementation and use of radio navigation systems.

My association with this discipline covers some 40 years stemming back to my involvement with the original work on aircraft blind landing and the determination of the orbital parameters of the first Soviet Sputnik in 1957.

I was actively involved in bringing the Omega and the Loran-C systems into civil use from DOD ownership and in recent years have devoted much of my time towards efforts to help realize the full potential of satellite navigation.

I appreciate the opportunity to be here to share with the subcommittee my views concerning the use of satellite technology in civil aviation. I understand my full statement, along with the attachment, will be included in the record; therefore, I will summarize my written statement by focusing on what I consider to be the most important critical issues that must be resolved in order to realize the potential benefits of satellite technology as it is brought into the inventory of aviation navigation aids.

I do not think you will find any disagreement among the panel of the benefits to be derived from satellite technology and the need for an orderly transition to this new environment. Nor do I think there is a substantive difference of opinion of how we go about this.

The United States Global Positioning System (GPS) is the guinea pig, and the FAA is doing an admirable job in flushing out the technical issues that challenge us on our way to adopting this technology. It is the definition of the final system that materializes 10 to 15 years from now that should command our attention.

GPS has been developed over the past 20 years by the Department of Defense at a very high but somewhat indeterminate cost to the American taxpayer as an integral part of the United States' national security strategies. We also talk of a Global Navigation Satellite System or GNSS, which is the international community's vision of the ultimate system of satellite navigation.

You may hear these two acronyms, GPS and GNSS used synonymously, particularly by those who see GPS as becoming the backbone of an international GNSS. This was not the intent of the offer for free use of GPS transmissions made by the former FAA Administrator Admiral Busey, in his address to the 10th Air Navigation Conference of the International Civil Aviation Organization in September of 1991.

It is with the definition of final GNSS that my views may differ from those of other witnesses at this hearing. GPS is presently owned and operated and funded at a direct cost of between $500 and $600 million per year. And this cost is to continue every year that GPS is in operation.

This does not include the indirect support costs of the worldwide tracking network, depreciation of these assets, and other costs that are addressed in my written testimony and attachment.

And I derive these costs from the General Accounting Office report which is also referenced in my written testimony. It is virtually impossible to determine the actual annual operating cost of GPS because the indirect costs are commingled with the overall Air Force classified and unclassified space activities.

But if the entire GPS operation and financial responsibility, including support activities, were to be transferred from the Department of Defense to the Department of Transportation to make this a civil system, as was Loran-C in 1974 and Omega in 1980, the total annual expenditure would exceed $1 billion.

The alternative to is leave the GPS operation with DOD, but this has major implications with the international community.

GPS, under this arrangement, is not internationally acceptable. Sharing of costs between DOD and DOT would make for confusion and not alter the perception of ownership.

The United States is on record with ICAO and the International Marine Organization to supply GPS transmissions without charge for the foreseeable future. Since the typical life of a radio aid to navigation is 50 years or more, by making GPS the backbone of the GNSS, we are committing the American taxpayer and user to a very substantial open-ended and, in my opinion, needless cost; and we are making a serious strategic mistake.

Cooperation with the international community to orbit a GNSS designed specifically for civil applications 10 to 15 years from now will result in a system having lower annual operating costs, shared between nations, and substantially reduce the United States' long-term financial commitment.

Unfortunately, interests in the Defense Department don't see it this way and wish to maintain the upper hand by denying civil use of the full GPS capability. It is claimed that, by maintaining a monopoly over the technology, possible misuse against United States interests will be diminished. This policy is creating the conditions for an independent international approach to the GNSS that will have the full accuracy capability over which the United States will have little or no control.

We are paying a very high price to maintain this temporary monopoly, both in monetary terms and in loss of leadership. The United States alone cannot prevent misuse of the technology. This must be addressed at the international level through ICAO and the United Nations so that such action can be condemned in the Security Council and appropriate remedies imposed.

The potential of system misuse must not become the reason for the denial of an important and beneficial technology for international civil aviation.

There are technical reasons for addressing the design of the ultimate GNSS. GPS was never intended to meet the full needs of civil aviation; and by making it do so, we are having to introduce a range of expensive augmentations some of which are designed to defeat the intentional degradation by GNSS.

The number of satellites in the GPS constellation alone is insufficient to meet the signal availablility and integrity requirements for a primary means of navigation. The very weak signals, with their current format, are vulnerable to intentional or unintentional interference. The issue of jamming of GPS signals during the final phase of flight by terrorists or even pranksters has been raised but has generally been dismissed because there is no precedence for this with current systems. This vulnerability of GPS should be given more careful consideration in light of recent terrorist activities.

We must become involved in international agreements. Bringing satellite positioning technology into the national airspace is complicated by the satellite system's global coverage. We could make a unilateral decision to employ GPS in our national airspace, but the full benefit to civil aviation will only be derived through international use of the technology.

The advent of global radio navigation has added a new dimension to international cooperation. This is seen with the Omega and Loran-C terrestrial systems whose introduction for international use was preceded by the generation and signing of international agreements.

These agreements and the procedures that led to their signing provide precedents for similar agreements covering satellite navigation. As you are well aware from your extensive experience in these matters, Mr. Chairman, there are specific procedures under United States constitution, including congressional oversight, which govern international agreements. And a detailed discussion relevant to radio navigation is provided in the attachment to my written testimony.

I will conclude by saying that navigation by satellite has great potential which, in my opinion, will only be realized fully when it is adopted internationally in concert with satellite communication.

Preparation for this must take place within the panels and committees of ICAO to be recommended for adoption by the ICAO Air Navigation Council.

In addition, an international agreement must be formulated and negotiated with the satellite service provider.

It could take up to 10 years to conduct this administrative support work. In the meantime, GPS should be used as a test bed to determine the capabilities and limitations of the technology as applied to civil aviation.

During this period, the United States should cooperate with the international community to implement a GNSS that would be funded, operated, and policed internationally.

Mr. Chairman, that completes my oral testimony. I thank you for giving me the opportunity to participate in this important hearing. I will be pleased to respond to any questions that you have for me.

Mr. OBERSTAR. Thank you very much, Mr. Beukers. And you are a contrary voice, a voice of caution. And it is important to have your perspective, and we appreciate the thought that you have given to this issue. And we will come back to those points later.

Next Mr. Watrous.

Mr. WATROUS. Good afternoon Mr. Chairman and distinguished Members of the committee.

Mr. OBERSTAR. Symbolically, the other end of the spectrum.

Mr. WATROUS. Possibly so, but I would hope not.

I am David Watrous, the President of RTCA. And I appreciate the opportunity to help apprise you and the Members of the subcommittee with the fundamental changes that are about to occur in civil aviation as well as the role that RTCA is playing in achieving that objective.

As Secretary Peña said earlier this morning, civil aviation will soon experience the greatest operational change to have occurred since the introduction of radios and radio navigation over 50 years ago. This change is driven by the need for increased capacity, efficiency, and safety.

Concepts for achieving this new operational capability have been discussed for many years. It is only now, through the combination of new powerful computers, satellites that can precisely and instantly establish the location of aircraft with an accuracy of 300 feet or better, and universal time with an uncertainty of less than 1 one-millionth of a second, and digital communications using either satellite or earth-based equipment that civil aviation can now achieve the enhanced capabilities it so desperately needs.

The resulting Air Traffic Management system will fully address the needs of aircraft users, airport operators, and the FAA and will truly produce an integrated and well-balanced system with greatly improved operational capabilities.

To move from concept to operational capability, the civil aviation community needs to coalesce user requirements, assess technology options, resolve institutional issues, then agree on a strategy and milestones for a transitioning to the ICAO Communication Navigation Surveillance Air Traffic Management system.

Consensus-based decisions are needed as to how and when the change should occur.

RTCA is in a unique position to help the community achieve these objectives. We operate as a Federal advisory committee, and our deliberations are open to all who have interest in our work. Our products are consensus-based recommendations that are used as basis for FAA and for business decisions.

We recently completed a task force effort that involved 200 volunteers from across the full spectrum of the aviation community and reflected community consensus as to how and when the community could transition to satellite navigation.

Based on the success of that effort, we are now drawing government and industry together to make similar recommendations regarding the transition to digital communications.

I have prepared a statement for the record discussing RTCA and how it operates as well as some remarks highlighting the results of our 1992 satellite navigation task force and our current Digital Communications Initiative. Both activities were requested by the FAA Administrator and reflect that agency's confidence in our proven record of developing community consensus on important communications, navigation, and surveillance issues.

In the case of Global Navigation Satellite System, Transition and Implementation Strategy Task Force, or the GNSS task force for short, the committee reached five general conclusions.

First, aviation system users need and want the operational benefits that will accrue with the use of GNSS.

Second, the technology required to achieve a GNSS initial operational capability is available.

Third, there are no institutional issues that should preclude achieving an early initial operational capability.

Fourth, the transition to GNSS-supported operations should be user driven and should occur in an evolutionary manner.

And last, initiatives to address and resolve issues attendant with the longer term use of GNSS should promptly begin.

The Satellite Navigation Task Force went on to note, in part, that satellite-based, automatic, dependent surveillance and the initial future Category I precision approaches are desired this year, in 1993. Category I precision approaches are desired next year, and a capability for satellite-based, auto-land capability using advanced signal processing techniques by 1997.

The task force emphasized that the transition from the use of current ground-based navigation equipment to a satellite navigation system should be based on the rate at which users equip with new satellite navigation electronics.

Furthermore, users who invest in the new technology should immediately be provided operational benefits in direct proportion to their improved operational capability.

At an appropriate point in the transition process, when the majority of users have completed the transition to satellite navigation, traditional ground-based navigation systems should be decommissioned thereby reducing cost to both government and industry.

The task force also suggested an innovative acquisition strategy to accelerate the operational use of satellite navigation and the benefits attendant therewith.

In total, the Satellite Navigation Task Force drew 64 specific conclusions and made a total of 116 recommendations. Copies of the task force report can be made available, sir, to support your deliberations.

The Satellite Navigation Task Force noted, in completing its report, that notwithstanding the many benefits associated with using satellites to determine the instantaneous position of aircraft, the full benefit of satellite navigation can only be realized by making better use of airborne and ground-based computers coupled with traditional communications.

The FAA Administrator accepted that observation and requested RTCA to conduct another task force. Our new task force is under way. It, too, is operating as a Federal advisory committee. Three working groups are hard at work. One is dealing with users operational requirements; one is focusing on institutional and transition issues; and a third is assessing technology choices and opportunities.

Already over 100 volunteers are contributing to the development of the community consensus on this topic. This task force plans to have its recommendations ready for the FAA later this calendar year.

Mr. Chairman and committee Members, these are exciting times, as have you heard earlier today. The need for change is clear. The technology to implement the change is available. The process for achieving consensus on the transition is in place. And the true government industry partnership essential to successfully implementing the transition is evolving.

The United States is well postured to lead the aviation community in achieving new levels of air transportation capacity, efficiency, and safety. The question before all of us is not if; it is how and when.

Ladies and gentlemen, the time for action is now. Thank you for the opportunity to address this hearing. And I would be pleased to entertain a question.

Mr. OBERSTAR. Thank you very much Mr. Watrous. And, of course, your complete testimony will be in the record. I have had the opportunity to read it in detail before the hearings, and you have an enormous amount of substantive information in here that I find very, very useful. I appreciate your summary testimony.

Next, Mr. Fleming.

Mr. FLEMING. Thank you, Mr. Chairman. I am Roger Fleming, Senior Vice President, Operations and Services, Air Transport Association of America.

I understand that my entire statement will be included in the record, so I will summarize.

ATA member airline interest in GPS/GNSS applications is strong and is reflected in the work program of the organization. This would come as no surprise to you since Mr. Ferguson, who appeared before you earlier, is a member of the ATA board of directors; and he has certainly heightened the interest of airline chief executive officers in this new technology.

The highest priority airline objectives in the technical work program are those that will produce early operational benefits: use of GPS/GNSS to fly diverse routes in terminal airspace to achieve precision approach capability and to permit reduction of separation and timely attainment of optimal routing and cruise altitudes on critical over ocean segments. To achieve these objectives focus at the present is on use of the flight management system capability in our more modern airplane types to accommodate these objectives.

Each of the work program elements includes a number of steps. For example, the Precision Approach Project started with more flexible routings in terminal areas, progresses to non-precision approach, and moves on to precision approach. And that is exactly the process that will be followed with the Continental Airlines applications in which Mr. Ferguson expressed interest.

The over ocean project starts with inertially derived aircraft position relayed to the oceanic ATC center by satellite communications link and transitions later to GPS/GNSS position data linked to ATC.

Ultimately, the objective of FAA and all the users is to transition to the ICAO Future Navigation Systems Air Traffic Management concept which will, when implemented, allow operators to fly conflict-free, user-preferred routings from departure point to destination.

This will require highly accurate navigation capability on the airplane, which clearly can be accomplished with GPS/GNSS technology; near instantaneous communications ability, Mr. Watrous has talked to you about the ongoing effort in RTCA with respect to evolution to digital communications technology; and a high degree of automation in the ATC system. The that latter has been the subject of a recent hearing that you convened with respect to the Advanced Automation System, relevant at some point in the future.

The transition to FANS will be costly, and it must be planned carefully to ensure that the introduction of benefits justifies the investments that will be required by both government and users. Focus on the early operational benefits can, we believe, drive the implementation process both within the U.S. airspace as well as in the international airspace.

And here, I might add, that the U.S. airlines are certainly moving aggressively to take advantages in both areas, domestically and internationally; we are working cooperatively with our international colleagues in the International Air Transport Association and finding a great deal of interest in that community as well.

The transition planning for how to accomplish all this, how to move from the current generation technology to GNSS and digital communications technology, will be critical to our success. The FAA and the airlines have been working together to pursue some of these early operational benefits that I have mentioned.

Again, Mr. Ferguson mentioned the significance of those benefits to his company and provided his estimates of the potential cost advantages. Other ATA member airlines are working with manufacturers and FAA on complementary development work. United and Northwest are pursuing over-ocean benefits associated with the introdction of automatic dependant surveillance technologies on the oceanic routes such as Los Angeles-Sydney. Among our colleagues at the table, David Haapala is involved with that. American Airlines is achieving Category I landing minimums using an integrated GPS/inertial navigation solution on a B–757 aircraft. This effort will be extended later in cooperation with Boeing and others to seek FAA approval of ultimately, Category III landing minimums.

All the activities I have just described are being pursued based upon the promise of safety and operational benefits that can, in the airlines' judgment, justify the cost of the necessary modifications of the airplanes.

However, the potential benefits are all dependent upon soundly planned and coordinated FAA and industry actions to carry out the transition to applications of the new technologies.

The evolution to space-based systems will be governed primarily by economic and institutional issues, not by technology.

The pace of airline equipment modification will be tempered by the requirement to achieve a rapid pay back on the capital that must be invested in the new technology.

And, here again, Mr. Ferguson pointed out that the potential benefits are other than those involving capital investment when he showed you the rack in the 727 that could be replaced by several small units.

The technology is available. The question is whether the Congress, the FAA and the industry, working together, can develop and execute a transition plan resulting in the implementation of these new capabilities in a reasonable time frame.

RTCA laid out the road map that needs to be pursued to implement GNSS. And Task Force 2, as Mr. Watrous reported, is working on digital communications which, in our judgment, is an even more challenging set of problems.

FAA has initiated a number of planning activities not all of them adequately coordinated with the airspace users. That should not be surprising. One of the reasons that is taking place is because things are changing so rapidly in the FAA as well as in the industry that it is very difficult for all of us to keep in harmony.

However, the user's view of what is needed and how the transition should be affected is not yet taken adequately into account by FAA in my judgment. And I believe Mr. Pozesky agreed this morning during your questions to him that a more rigorous approach to that problem is going to have to be pursued.

The airlines in the United States have been critical of the FAA timetable and milestones laid out in the FAA Satellite Navigation Master Plan and other related documents. We are all going to have to exercise imagination and leadership if we hope to realize the potential advantages of satellite technology in a reasonable time frame.

We hope that you will be able to assist us in achieving these goals, Mr. Chairman, by urging FAA to: one, develop a single, integrated plan in consultation with the users to implement the new technologies for the purpose of realizing the safety and operational benefits for the government, the U.S. manufacturing industries, and the users; two, to develop and put in place a management structure and process to ensure that the diverse efforts of FAA are all pulling together in a coordinated manner and time frame; and, three, to identify any additional resources that may be required to execute the program.

Finally, I would like to note, Mr. Chairman that none of the technology applications that we are discussing here today will be worth a great deal without fundamental changes in the way the air traffic control system does business. Some significant changes are going to have to take place. And the current mode of operation and experience indicates that introducing change within the air traffic control system is not easy, either in the United States or outside the United States.

Thank you, Mr. Chairman.

Mr. OBERSTAR. Thank you very much, Mr. Fleming; and to that latter point we shall return. I assure you that that raises some very important questions for me.

And now, Captain Haapala—that is a good Finnish name.

Mr. **HAAPALA**. Thank you. I am Dave Haapala from Northwest Airlines. I am Director of the Flight Technology Group at Northwest. I, too, have a written document for you to look to, but I will paraphrase that and summarize that in my oral testimony now.

I echo the statements made about enthusiasm for this new system, particularly Mr. Ferguson's remarks this morning. But I also will be indicating some frustration that goes along the lines of that just expressed by Mr. Fleming.

When you look at it from this point of view, that in 1983 ICAO first began work on its definition of new future air navigation system, in 1987, four years after that, it published its report on the FANS system; and now here it is 1993, and we are just barely getting started on this new navigation system. And we are talking about 2015, according to one plan I have seen of the FAA's, before we see a full implementation of this system. In our view, this is just taking too much time.

We say that because the operational and economic implications of the new airspace system are enormous. The FANS report states that there could be savings of $5 billion a year in reduced fuel usage and time, based on better routes, altitudes, and fewer disruptions. Along with better communications for our airlines operations control, and we could reduce avionics cost. That was demonstrated so vividly here this morning with the display of the avionics that could be taken out of the airplanes and replaced if newer, more capable, more universal systems that can guide us all the way from taxi through takeoff, through landing and taxi back in again.

And this new savings also comes with a much more capable system in our view. We have studied these systems, both the navigation systems and the communications systems; and we believe eventually they will be replacing ILS and can eclipse MLS. And I recognize that that is not without some controversies, especially in Europe.

But also, it can take out all of the other serial systems that we have now, such as compass locators and automatic direction finders and VHF navigation.

And it can also take out this 1930s shortwave like HF system that we still rely on for oceanic communications.

Let me give you a quick anecdote. Just the other day one of our airplanes crossing the Pacific from Los Angeles to Fiji had onboard a new voice system, one of those that we are testing in the Pacific intertial trials.

A woman passenger suffered what appeared to be a heart attack en route somewhere near Fiji. The captain was able to make a quick phone call in a matter of seconds to our operations control in Minneapolis, and they patched them into the Mayo Clinic in a matter of seconds and to the controllers in Fiji, and they had a four-way conference call set up in less than a minute. The Mayo Clinic was able to advise the crew that they believed that the woman was in danger from a heart attack, and they were all in process before they had to make the request. All of this as a result of satellite communications which we are only now beginning to introduce.

Northwest is also very active in the promise of enhanced vision, as we call it, which is a combination of the space-based navigation system and then relying on for the last few feet for the pilot to talk over eventually using a heads-up display and millimeter wave or infrared to complete the landing. And if you have any questions about that, I would be happy to talk about that.

We believe that coupling these two systems together will allow even the most modern airplanes, the A–320 or Boeing 737, to make similar landings at Duluth, Minnesota, Mr. Chairman, or Omaha or Fargo, Rochester, Shreveport, many of these airplanes that do not have the Cat II, Cat III capability.

The frustration is that we have all of these systems that we are ready to start to put on our airplanes. We believe that the technology is reasonably mature. There are some questions that still must be asked. But we don't see the benefits that we need to get from these things to pay for these systems in the near term. And the reason we don't see the benefits is because the whole infrastructure is not yet in place.

A few months ago, at Reston, Virginia, I addressed a conference there on worldwide navigation; and I used the analogy of Edison's light bulb invention at the close of the last century. It was a marvelous invention that every school child knows about; but it wasn't until the invention of the electrical network system that came later that the light bulb was useful.

That is the same situation that we are facing today, we need the whole system in place; and that system is not only the communications network and link between aircraft and the ground or the navigation accuracy that we put on our airplanes but the ability to use them. Because the air traffic control system is similarly equipped with modern computers and enhancements to be able to communicate in information more readily.

Now why doesn't this system come into place more rapidly? In our view, in some respects, it is nearly stalled, to use the aviation term. Simple changes, such as pre-departure clearance and Automatic Terminal Information, ATIS, that we have been trying to introduce over the last few years are only beginning to start. We have got pre-departure clearance at 30 some airports and ATIS at two airports, two things the pilots want very, very badly.

We have oceanic clearance across the North Atlantic but only in one direction. And we have been in the process of developing that for four years. It is simply coming too little, too slow, in our view. If we keep on that migration to the new systems, it is going to leave us with what I call a benefit gap, the time between when we want to equip our airplanes and we start putting the money forward and we actually start getting some benefits from it.

I want to quickly say that the problem here, in my view, is not the people; it is not the organizations. We have got talented, energetic people in this industry. We have marvelous organizations, both private and government organizations, that are well managed and organized. But, nevertheless, we are still missing the point.

There are some reasons that I have spelled out in my written testimony, and I will summarize them here.

Part of it is because the aviation industry is so diverse, it is so vast in its scope, and it is so complex that we have so many organizations and disciplines involved in it. We have everything, such as consensus bodies, as SWC, the Airline Electronic Engineers, and

RTCA, that Dave Watrous represents here. We have market-driven organizations, the aircraft manufacturers, the avionics vendors, the airlines, and to some degree the service providers such as AIRINC or SETA. And we have advocacy and advisory groups that include organizations such as AOPA, the NBAA, ATA, IATA, and think tanks from NASA to Lincoln Laboratory, and so on.

And all of these organizations have subgroups. And many of these subgroups are meeting just as we speak and using extremely arcane language, I call them acronym-laced language that, in many ways, causes this whole process to become a tower of babble where almost nobody knows what the overall picture is and very few people can even have a good idea of some other important aspects of this overall process that needs to be going on.

Another problem we have is too much allegiance to personal interest. Someone representing an organization merely has to be concerned about protecting what is dear to that organization and doesn't have to be concerned about making a compromise that is necessary to give in to somebody else's special interest in order to get the overall job done.

And there is no overall implementation plan, organization, or accountability. I recognize that the FAA—and it was testified to here this morning—does have a plan. They do have people. They do have procedures and so on in place. But I am talking about a larger organization than that that encompasses more than just the government but also private interests as well in a partnership arrangement. And I will have a couple of more things to say about that.

And this must include, as I know you have pointed out Mr. Chairman, not only the experts from the industry, that is the technicians and the engineers, not only the government personnel or ICAO personnel in the international scene, but also controllers, pilots, also dispatchers, and people not only who are experts, technical experts but also have some proven innovative expertise as well in working with other people.

There is also the issue of too much bureaucracy, and this is not intended to be criticism of any particular group, either inside or outside of government. That is a fact of life any time we have a large organization. And particularly the hierarchical organization that we use is not necessarily working very well for this type of a program.

And I would suggest that we do use a management structure somehow like Mr. Pozesky talked about this morning, which is a team approach that is used in Detroit by his organization and could be applied across the industry both in government and the airlines or other private institutions as well.

For the airlines, too, there is too much emphasis on—past emphasis on volunteerism. And this may seem strange because volunteerism, of course, is a noble pursuit and we cannot live without that. But the airlines very engineers had to put personnel on these types of problems through various ocean organizations. And they just no longer can do that.

So, therefore, that type of user is no longer coming to the various forums where these development processes take place. Those people must be brought back into the forum, but they must be brought back in such a way that they can cover their costs. With all of these things, we have several results that do occur that are not what we would like them to be.

We do not have enough control over the overall process for the users and the airline's point of view. We don't have enough of our inputs, enough of our validation, enough of our programming view in the process from our point of view, just not enough activity that we are actively involved in.

Therefore, some of our operational solutions as technical solutions cannot be applied. I have seen this happen from my point of view too many times where the engineers only look to the technical solution when there is a pilot or controller an operational or procedural solution that may solve the problem much more simply, quickly, and less costly.

There is also in many of our institutions no urgency, really, to complete anything. And, therefore, development dollars are sometimes wasted, and operational improvements that could save the airlines billions of dollars a year languish.

That is the conclusion of my verbal testimony, Mr. Chairman; and I thank you for your time.

Mr. OBERSTAR. Thank you, Mr. Haapala. I am very much appreciative of your presentation. And you have raised some important points to which we will return later.

Now, Mr. Brown.

Mr. BROWN. Thank you, Mr. Chairman, Members of the subcommittee.

I am Steven Brown, a Senior Vice President, Government and Technical Affairs for the Aircraft Owners and Pilots Association.

AOPA represents 310,000 individual aircraft owners and pilots who fly aircraft for business and personal transportation needs. And we now represent nearly two-thirds of all the aircraft owners and pilots in the country.

I appreciate the opportunity to appear before the committee today to comment on the efforts that FAA has under way to integrate satellite technology in their airspace modernization plans.

Mr. Chairman, I am pleased to note that significant progress is being made in this area from our viewpoint. FAA has a number of ongoing, very aggressive research and development projects which will lead to capacity and safety improvements in the near term.

The aviation community, as you have heard from Mr. Watrous, through RTCA is actively identifying satellite application opportunities and establishing industry standards that will enable airspace system users to extract the operational benefits from the equipment that they will purchase in the future.

We at AOPA have been leaders in each of these areas and have a continuing involvement with FAA in cooperative demonstration projects that are now focused on improving the benefits of GPS precision approaches and landing in general aviation aircraft; the equipment that you saw on the table.

The local differential we have had operational at Frederick, Maryland, where we are headquartered for the last two weeks and are flying in a single engine aircraft. And I invite you and any of the other Members of the committee that are interested, and staff, in the time that you might have available, to come and participate in those demonstrations if you would like.

It is ironic and revealing to us that satellite technology was barely mentioned back in the original NAS Plan. It clearly holds the most promise for future benefits in the future system and clearly will offer more affordable and efficient use of the airspace.

As you know, we have long maintained that satellite technology should be the core and the centerpiece of future NAS, which is now called the capital improvement plan. And clearly advancing technology over that 12 years has overtaken much of some original NAS Plan.

As you commented this morning, Mr. Chairman, the Microwave Landing System is a classic case of this very premise that we have laid out many times and believe that this billion dollars that can be saved by economizing on the Microwave Landing System is essential for the future.

As you know, the industry is facing higher taxes and fees, and saving on future programs like that will be essential in preserving jobs, manufacturing and productivity, as well as competitiveness in this sector of our economy.

The core of the plan that I would summarize for you, Mr. Chairman, has to do with FAA management challenges in the future in the area of satellite technology.

As it attempts to implement the technology that we have all talked about today, I believe that FAA faces a number of major challenges.

As you know, Mr. Chairman, the FAA is organized as a highly interdependent agency. When new technology is implemented, it requires FAA to perform research, conduct demonstrations, specify standards, grant certification, establish procedures, and alter air traffic control methods.

If any of these necessary activities are managed poorly or lag seriously behind the others, the inevitable technology will not be developed, and the users will not receive the potential benefits that they have invested in. Therefore, it is essential, in our view points, that FAA make measurable progress in all of the areas that I have mentioned at a similar pace and with common objectives.

In the satellite programs, in particular, we believe that FAA is either behind or struggling to stay at pace in a number of critical areas. From our view points, the procedure development process appears to be nearly dormant, especially as it relates to new satellite procedures.

In addition, the pace of air traffic control adjustment to new methods and airspace organization concepts appears to be glacial. I believe FAA risks the devastating legacy of having defined, demonstrated and certified new satellite technologies, but potentially failing at establishing procedures and air traffic control policies to enable the benefits of increased system efficiency, capacity, and safety.

I hope that Mr. Pozesky's forecast this morning that some of this lack of supervision is due to communication problems more than substance holds to be true, but I am looking forward to that communication. For example, we believe that while FAA has approved GPS for overlay use of existing approaches, it has not developed even one new approach procedure to one of the many thousands of airports that would perceive instrument approach guidance for the first time, and FAA has failed previously to develop such procedures for Loran-C technology that would have offered instrument flight benefits for the investment and equipment that more than 100,000 general aviation payments made.

And this very area was a focus of questioning between Mr. Clinger and Mr. Broderick this morning.

Clearly the substantial savings of benefits inherent to transitioning to the system in the future are far too great to pass up. We believe that it will save billions on some of the existing CIP programs which will be unnecessary or incompatible with the new satellite system.

Mr. BROWN. Last thing, Mr. Chairman, I would like to note in summary, that while we are encouraged with FAA's recognition of the benefits that they have highlighted throughout the day today, and are especially encouraged by Secretary Pena's inaugural appearance in front of this committee on this issue as being a very significant mark of the administration's support for satellite programs, we still believe there is a need for increased management focus and leadership on FAA's part that satellites are the way of the future and should be the centerpiece of FAA's modernization initiative throughout the rest of this century.

We believe that FAA must overcome the management challenges I have tried to outline and must prove its ability to design procedures and air photographic control changes that will enable the user benefits that we are all investing in. We urge the committee to help keep FAA focused on the need to look forward rather than back on some old technology, and we believe the results will be billions in savings compared with some of FAA's original intentions in technology development.

Mr. Chairman, I thank you and look forward to your questions.

Mr. OBERSTAR. Thank you very much for a very good review of the subject matter.

And now, Mr. O'Brien.

Mr. O'BRIEN. Thank you, Chairman Oberstar.

Mr. Chairman and Members of the subcommittee, I am John O'Brien, Director of the Engineering and Air Safety Department of the Air Line Pilots Association. ALPA represents the professional interests of 42,000 pilots flying for 44 airlines.

In the interests of time, I will shorten my already short statement, which is only about four pages, to a page and a half.

We have heard many benefits, both economic and safety, associated with satellite technologies. Rather than reiterating those benefits, I would like to just indicate one concern that we have associated with our ability to achieve or make maximum use of these benefits. That concern is that we, the collective we in this case, the industry and the government, may not have adequate resources to mount the effort required to achieve these maximum benefits at the earliest possible time. In this case I am talking about the grandiose satellite scheme, the FANS scheme referred to earlier.

We can't afford to put up another satellite constellation; the users nor the government can afford this. We have one in existence today so I am going to concentrate on how best to use that system

I am going to speak from the perspective of this country because the 44 airlines I spoke about are interested in economics and safety benefits associated with operations conducted primarily in this country and over the oceans surrounding this country. There will be a natural carry-over to other countries.

The effort required on the part of the industry and government has many components. I would like to focus on what we believe is the most critical. That component involves defining the operational requirements for both airline and general aviation use of satellite technologies and the criteria that FAA will use to either certificate the hardware and software associated with these technologies or the guidelines that FAA will use to approve the operational techniques.

Today advisory committees like RTCA, that Mr. Watrous referred to earlier, play an important role in this process. They are the ones that develop the industry consensus and provide the criteria from which FAA develops its TSOs or other regulatory or guidance material.

As Mr. Pozesky and Mr. Broderick pointed out, there is a TSO for GPS receivers. It is the only one and it is not applicable to airline use. It doesn't address many of the broad applications that are necessary. So there is much more work to be done in this area.

That is not a criticism on FAA. That is a criticism on industry because we need to get together, we need to decide, as Mr. Ferguson indicated earlier today, what it is we want to do and how we want to do it. Once we decide that, then FAA can define its certification criteria and manufacturers can build the hardware and software necessary to fit those operational requirements. We are not performing that task very well today.

As Captain Haapala pointed out, there are several groups that are involved in this process and we need to define a focal point to collect all this activity and maybe RTCA is the place to do that. RTCA has played a significant role in the development of certification criteria for many avionic systems.

If the picture I just painted is accurate, and I believe it is, how do we move towards rapid implementation?

Well, first let me build on what Secretary Pena discussed this morning. If he is truly committed to seeing the benefits of GPS or other satellite systems, one of the things that maybe this committee could do in conjunction with the Secretary is look at the cap on spending for advisory committees.

The FAA finds itself in a very difficult time today or position today. It cannot provide the resources necessary for advisory committees like RTCA to function in the role that they were designed to do. So that may be the first thing you might want to look at.

Second, we need a clear and definitive direction jointly established by FAA and industry, in other words, a road map for early implementation. Again, I would just second a lot of things that Captain Haapala said in this case, but without that clear road map, we cannot orderly transition to a system that involves many of the components that are necessary to support GPS like the digital communications link that was referred to earlier today.

And third, pending adequate FAA advisory committee funding and development of this clearer road map, our industry must be willing to commit resources for the development of this material.

Yes, airlines are in a difficult financial position today, but given that clear road map, given the focal point, I am sure that Northwest and other airlines will provide the resources and the personnel to participate in this industry consensus development. I know that there is one organization that is committed today and I will go on record as indicating that the Air Line Pilots Association will commit the resources, staff, time and effort to do this.

In summary, we believe the present satellite systems have significant communication, navigation, and surveillance capabilities. However, these capabilities are not being used in a manner that provides maximum benefit to aircraft operators or government agencies who must provide the services to these operators.

That refers to the ATC question that was brought up earlier. Very little pure research or engineering is needed in order to greatly increase the use of these capabilities. What is needed is rapid definition and development of industry consensus on the operational requirements and on the technical data which will be used by FAA for certification and the operational approval of the hardware, software, and operational techniques associated with these requirements.

The Subcommittee on Aviation can play an important role in this process, Mr. Chairman.

Thank you for the opportunity to testify. I will be happy to answer any questions at the appropriate time.

Mr. OBERSTAR. Thank you very, very much, Mr. O'Brien. We greatly appreciate your perspective and that of the Air Line Pilots on this important matter, and I have some points that I will come back to.

Our final witness of this panel, Mr. Poritzky, who has a very long association with this subject going back to your years with the FAA. You were there at the formulation, at the creation, as it were, of this technology and now you continue to pursue it from a different perspective. And we look forward to your observations on these technology operations and its application.

Mr. PORITZKY. Thank you. Thank you, Members of the subcommittee.

I am Sieg Poritzky with the Airports Council International representing the major airports of North America.

We believe that GNSS/GPS—and I use those terms advisedly—will be a major element in the technology of airport and system capacity and in the essential coupling of the airport and the air traffic management system. I want to report to you on the recent action of the Board of the Airports Council International-North America which recognized that system integration and better information flow, which most of us here have talked about, are the keys to a modern aviation technical infrastructure.

Our Board endorsed an integrated policy of several elements: The Global Navigation Satellite System, whose correct definition, I believe, the system of several satellite services to which the GPS is the major U.S. contribution, is expected to be the primary navigation system enroute and especially in terminal areas, along with the Microwave Landing System for Category 2 and Category 3 final approach and landing guidance.

We believe GNSS alone is expected to serve all navigation needs for many aviation system users, sooner rather than later. Differentially augmented GNSS, we believe, as does FAA, is likely to support operations to at least Category 1-equivalent minimum.

We support the early completion of the development of a simpler-than-currently-specified, but a Category 2- and 3-capable MLS, as I will mention in a few moments.

We strongly support the work to explore the possibilities of GNSS, supporting Category 2- and 3, but we think it would be foolish at this point to abandon that element on MLS "betting on the same". We won't know for several years whether it can be a reality for all aircraft.

The airport operators believe that GNSS-based airport surface traffic management would significantly improve airport operations, and thus GNSS is the approach of choice for airport surface operations.

Development of terminal and on-airport automation systems—I am echoing what Roger Fleming said a few moments ago—should proceed in a way fully integrated and harmonized with more-capable air traffic control and flow management techniques.

World standards of broadly applicable digital data link communications fully applicable to satellite and terrestrial communications are crucial. It is not hard to grasp, from these views of the Airport Operators' Board, that the days are gone when we could consider the air traffic control system and the airport surface management system separately. Those days are gone, and good riddance, if we are to gain the real benefits from the synergism that is the key to aviation's future.

I would like to step back for a moment and add some thoughts from the perspective of a former member of ICAO FANS and offer you a slightly different perspective than you have heard. The backdrop is that the United States has been a strong supporter, a leader and a major financial contributor to ICAO since it was formed at the instigation of President Franklin Roosevelt late in World War II.

It is also appropriate to recognize that FANS, was formed because the ICAO Council itself reluctantly agreed that it would have to move more rapidly than it had moved in the past if technology was not to pass it by. ICAO FANS in some respects was a watershed for ICAO, because it recognized that the mechanism it was operating under, then with fewer states but now with 179, was simply too ponderous to manage quickly to create change.

With the strong leadership of Canada, the Soviet Union (at that time), France, Netherlands, Australia and the United States, the ICAO Council established FANS as a Special Committee to make change, to find ways to change to utilize the new technology.

I think what I am saying here will be corroborated by Admiral Engen, who is with us today, who was the Administrator of FAA at the time, and my boss. I know he expected change to occur out of the FANS activity.

There have been several old arguments raised anew about GNSS availability and management, its beginnings as a military system, and other allegations that are potentially destructive to the aviation revolution that GNSS can trigger. The charges aren't new. They were brought up by one or two States when the United States first made its offer of GPS to ICAO FANS in 1984 and 1985. The arguments had little credence then or now.

We have a summary of those charges and some comments on them which we will be pleased to make available to the subcommittee. Similar comments were offered by RTCA a few weeks ago.

One point to clarify is the term GNSS. Contrary to what you have heard this morning, the first United States offer of GPS was not made by Admiral Busey. It was made at least three years before that by the U.S. FANS member. It was done after more than a year of consideration within the United States and the Department of State, Department of Defense and Transportation. And it was offered right from the beginning as a contribution to a world system.

The term GNSS, Global Navigation Satellite System, was coined I believe by Jan Smit from the Netherlands, the chairman of FANS at the time from the Netherlands at the time. The U.S. offered the GPS availability to 100 meters accuracy at no cost to the users. It was complemented by an offer of the then U.S.S.R. of the GLONASS system on similar terms. GNSS was defined then as a combination of those two satellite systems plus others, which both of the States making offerings welcomed, in order to overcome some of the very concerns that have been expressed, and to create a satellite system that was better than either of the systems alone.

Those are the facts of the formation of GNSS. It is also why it is so important that we consider GNSS as a unified system.

One small sidelight: Some time before the United States made its offering, there was consideration in FAA as to whether FAA should move forward with GPS or consider a purely civil satellite system. A study was done for FAA by Lincoln Laboratories. Then-administrator Admiral Engen will remember.

The question was: how much less expensive would a purely civilian system like GPS be? The answer turned out to be about 85 percent of the cost of the GPS. The European Space Agency did a similar study, by a Canadian consultant, with similar results.

The reason I dwell on this is that, of the perhaps $12 billion investment in GPS in the United States, (and equivalent in the Soviet Union I expect), we would have to find $8–9 billion to build a new one. I haven't seen many people lining up to spend that kind of money in Europe or the United States.

Let me return, now, to what FAA must do next. I believe, and my Association has said so, that FAA is doing better on this program than they have done on many, many others. As you may know, I am not an unalloyed booster for FAA.

FAA's top management is committed to moving rapidly. Top management has shown its willingness to work with the industry in several ways, as has already been discussed.

I agree, of course, and my Association agrees, that there will need to be continuing vigilance, pressure, and involvement from the user industry in all kinds of ways to keep it moving, because that is how our system works.

Let me close with two points. There are several areas where FAA needs to concentrate its efforts now. We agree that the most important task is for FAA to find better ways to develop the new procedures which the GNSS makes possible, and to do it quickly. There is some automation required, there is a way required to do procedure development in better than the retail fashion in which they have normally been done.

There has been much discussion of the differential transmission medium which is essential for GNSS. An early decision is essential. There has been much emphasis, as you have heard, on early achievement of providing Category 2 and Category 3 landing capability for GNSS.

This is laudable and airports support the work, but it may not be the most important consideration. Here again I use the term GNSS because the prospects for Category 2 and 3 go up very significantly if we can count on a half a dozen GLONASS satellites along with GNSS.

While Category 2 and 3 operations are important, there are other things, from a system perspective, that are more important.

Automatic Dependent Surveillance, in which automatic transmissions of navigation position are used to create a "pseudo-radar", and other functions will be important for general aviation as well as commercial. The remarkable capability of GNSS combined with Automatic Dependent Surveillance needs to be exploited rapidly as Captain Haapala and Roger Fleming have already discussed.

We need to make a series of decisions on digital communications, for they are crucial to creating the modern system we want. GNSS may be the source of the long-sought-after "talking beacon" which can continuously make the location identification, and altitude of all aircraft known to all others in the Air Traffic Control system.

GNSS might become the data source for a collision avoidance system far simpler than the current TCAS, and we believe this examination is getting under way. GNSS, we think, may serve as a simple inexpensive data source for Precision Runway Monitors.

Another area where FAA's analysis and evaluation is essential is the matter of interference. As has been said, the very characteristic which makes GNSS/GPS so attractive, its world coverage from the surface up, also makes its necessarily weak signals vulnerable to interference and intentional or unintentional jamming. We are all aware of this. It is not a matter for panic but for prudent action and precautions.

As Marty Pozesky said this morning, all radio systems including ILS are subject to interference and jamming by skilled persons. Continuous vigilance is required.

You heard this morning about the RAIM, the receiver autonomous monitoring. There are also other ways of providing integrity and protection against unlawful interference. It is important not to blow this problem out of proportion. The existence and use of GLONASS along with GPS as part of the GNSS, now not 15 years from now as soon as the GLONASS satellites get up, as envisioned by FANS, offer a significant amount of additional protection against unlawful interference by having both system constellations. Well-designed local differential transmissions will also play a role.

Let me close by making my most important point, underlining something Roger Fleming said. Satellite navigation, as important as it is, and I believe it will create a revolution, is not the most critical element of the needed system modernization. GNSS is not an air traffic control system and will never be one; it is only a sensor that a good Air Traffic Control system can use.

Better navigation by itself is of limited value if the Air Traffic Control automation and digital communications are not there to improve the air traffic control process. It is instructive to recall that FAA developed and demonstrated the principles of Automatic Dependent Surveillance in 1972. It went nowhere because there was no Air Traffic Control automation and no data link to make it useful.

While satellites are important and they are certainly glamorous, the major benefits to the users will come from the marriage of satellite navigation and communications with Air Traffic Control automation, with integrated flow management, with a real-time digital communications system and with exploitation of the airport capacity technologies which the industry has long pressed.

Thank you, Mr. Chairman.

Mr. OBERSTAR. Well, I thank you very much.

Mr. Poritzky, and to all of the members of this panel, I have been making notes as all of you have been speaking and reviewed the questions. I had also read your testimony over prior to the hearing and I have got enough questions to keep us going until probably 7 or 8 o'clock at night. We don't have time and you don't have time and I am not going to perhaps pick on any one of you.

What I am going to do is ask you to, whoever chooses, come forward to answer as succinctly as possible, the first I think and most important concern for us as policymakers on the authorizing committee and for the appropriation process in the Congress is to be assured that the FAA really is on track, as Mr. O'Brien said, has a road map for implementation, as each of you has emphasized, is on track with this system.

Are you really convinced that FAA is ahead of the curve as they have said, as many others have said, that they have a master plan, that that master plan is solid, that they are coordinating with the user groups and integrating into their development of this plan all the concerns and responding to those concerns, that in short, there are no apparent areas for slippage?

All of you, with the exception of Mr. Beukers, would like to see this whole concept delayed until it becomes a truly international one, want to see it move ahead as quickly as possible: Yesterday.

Identify for me, first, your confidence, points of confidence and your points of concern about the process which FAA is following and how we can together make sure that they stay on track, that all of you together stay on track. You are all part of this thing. You all got to help. 1040 short form answer, please.

Mr. BROWN. Mr. Chairman, let me start. It is a complex question and I will try to be to be succinct.

I believe and one of the things I highlighted in my statement—I believe Mr. Fleming and Mr. Poritzky did as well—are that the shortfalls of FAA at the moment are the procedure developments that we can all fly from our various perspectives and also getting the air traffic control part of FAA, the largest part in the past that is focused in the short term to understand the tremendous benefits for us as users and the benefits for FAA in terms of system capacity and safety. That is where the shortfall is on the procedure side and the air traffic control side.

The rest of FAA is doing very well and the leadership there is focusing on the future in implementing this system, but in those two areas they are clearly lagging behind from my perspective.

Mr. OBERSTAR. Mr. Haapala.

Mr. HAAPALA. Yes, Mr. Chairman. I might just say specifically that such things as an oceanic work station that will support automatic dependent surveillance in those regions in my view is on the critical path and too far out on the critical path for us to get the quick benefits that we need. It is the ground infrastructure, specifically in the air traffic control centers, that needs automation faster.

Mr. OBERSTAR. It is clear that oceanic navigation opportunity that is so attractive, had we had a GPS system operating and functional at the time of KAL 007 it might not have occurred. The pilot might have been able to query the GPS, find where he was and find he was way off track, and to believe the GPS rather than the onboard computer system into which he had incorrectly entered the coordinates.

Mr. HAAPALA. But the important thing is, Mr. Chairman, that if the ground controller did not know where that airplane is going and there still is a possibility of a procedural error taking place where the crew is unaware of diversion from their proper course, the ground controller must be able to see using ADS that that airplane is deviating.

All the accuracy in the world doesn't do any good until that ground controller sees that inaccuracy and actually can do something about it.

Mr. OBERSTAR. I won't pursue this matter further but there is a matter of some minutes of ACT tape from the Aleutian Islands chain that leaves that all open to question.

Mr. Poritzky, your concluding statement is somewhat troubling and that the major benefit to users will come only when you have ATC automation, integrative flow management, real-time digital communications joined with GPS. Is that on track?

Mr. PORITZKY. No. You had the hearing recently on the advanced automation system.

Mr. OBERSTAR. Yes.

Mr. PORITZKY. There were two messages there. One was that the Advanced Automation System, in its broadest sense, is intended to pull a lot of these things together. But only the fundamentals were being worked on. If you recall the testimony of the industry presented by Jack Alcott and the message from Joe Del Balzo, who is the Acting FAA Administrator, he said that something slipped "between the cracks" in the development of AAS, that the major benefits to the users which comes from the Automated Enroute ATC function (AERA), terminal automation, and automation of the flow process had been pushed aside. I believe he attributed it to inattention at the very top at FAA.

I believe that in answer to your earlier question, you can't get a much better team than Pozesky and Broderick and the SOIT to make GNSS happen. I think it involves continuous pressure from Mr. Haapala, from Mr. Fleming, from all of us to keep it going, but it also requires an FAA Administrator who will pay attention, who will keep pushing it regularly. It won't happen by itself; the attention of the administrator is crucial.

Now, to the other elements of this, flow management and automated air traffic control, the AERA system we have heard about for so many years will not work separately. They have to work synergistically. They have to be pulled together.

One of the major issues that FAA has identified, and all the rest of us have as well, is that these efforts must come together. The standardization, and the deployment of digital communication are crucial to what every airline wants and what most every user wants. We need to help create a system of aircraft flying the tracks they want when they want to go, barring other airplanes in the way. It requires a sharing of responsibility between the airplane systems and the ground. The connection is good navigation and digital communications so that these things come together.

In Africa, in South America, many parts of the world, GNSS will do wonders all by itself. It will create its own revolution. In a dense traffic environment we need all these things working together.

Mr. OBERSTAR. Fair enough. Mr. Clinger.

Mr. CLINGER. Thank you, Mr. Chairman. I apologize for not having been here to listen to the entire panel. I am interested in the comments that I have heard since I did arrive.

This morning I was questioning Mr. Broderick and Mr. Pozesky about the concern that some have expressed about the gap that may exist between the deployment of the satellites which will be in place and the system being in place and the fact that the procedures will not be in place. Mr. Pozesky seemed to be reassuring in that regard that that was on line, on track, that we were going to be in synch, that the system would be able to be operational because the procedures will be in place.

You seem to be not so sure of that. Is that a correct observation?

Mr. PORITZKY. It requires continuous pressure. There is a requirement for modernization in the way procedures are developed. FAA realizes that the way in which procedures are developed needs to be done better than in a retail fashion.

There are thousands of these procedures and we have to find ways to do them in groups. There is a good sign, I think, as Tony Broderick said this morning, in that there was a broad-scale approval of GNSS/GPS for supplemental use in recent months, but I would prefer to have Roger Fleming talk to this point and perhaps Steve because they are more directly involved in the procedures.

Mr. FLEMING. Thank you.

If I might continue upon Mr. Poritzky's offer, we have all talked about the problems we feel may arise with respect to lack of adequate and timely ATC procedures. The new technology applications alone will not do a great deal of good for the user community.

If, for example, the general aviation pilot is not able to make an instrument approach to a runway that hasn't previously had that ability because the FAA procedures development organization has not gotten around to developing that procedure. Right now I believe the FAA routinely develops about 300 such procedures a year, if memory serves me, and yet there are thousands of runways in the United States for which there is going to be very quickly a demand for instrument approach procedures from the general aviation community.

And FAA does not have the capability to develop those procedures quickly for the airline user. It does no good for Mr. Haapala to be able to navigate his Northwest 747 across the ocean if there are no FAA procedures in effect to enable him to take advantage of reduced separations. Right now if he is able to data link his inertial navigation or GNSS/GPS position to the Oakland Oceanic Center using satellite communication, there is a human being radio operator who sits in the midst of that linkage and still does it the old-fashioned way as there is no data communications link between the ground earth station and the air traffic controller. There is no oceanic work station that Captain Haapala referred to for the air traffic controller to use to assist in automation of his functions.

In the domestic airspace in the United States, it won't do the airline operator a great deal of good to have GPS precision approach capability if the criteria that govern the development of those procedures don't take into account the accuracy capabilities of that system to reduce the obstacle clearance zones and those zones are applicable to all classes of procedures. So these are the kinds of things that have clearly got the operators' representatives here worried.

I would like to add a few other thoughts in response to Chairman Oberstar's earlier question about the short form 1040 response. I certainly agreed with the comments that my colleagues Sieg Poritzky and Steve Brown made with respect to emphasis on air traffic control procedures and criteria, and that is obvious from my continued response to Mr. Clinger's question.

I would like to add some additional thoughts. There is no master plan at the FAA, as Mr. Poritzky said. There are elements of such plans available, but at the present time there is no master plan to which the users have agreed. In fact, to be honest with you, there couldn't be yet because, as Mr. Pozesky noted, he is awaiting recommendations from RTCA, for example, on the data link mode for communication of the differential message to the airplane. There are some other very difficult and knotty technical issues that remain unresolved.

One of the big risks for the users in early implementation of modifications to their aircraft equipment package is if they implement some capability that FAA later decides is inadequate for some reason or another, they will have to go back and redo the retrofit. That is incredibly expensive and frustrating and everybody worries about getting booby-trapped in that fashion. You bet on the outcome.

That is what Mr. Ferguson is going to do with respect to the Continental operation. He is going to do it first with a small number of airplanes so at least if they don't get it all right and don't satisfy all the FAA certification requirements the first time around, at least he won't have very many airplanes that he will have to go back and redo.

We have to got to reach an agreement between the certificating agency, the FAA, the air traffic control provider, the FAA, and the users represented at this table, and the pilots, as to exactly what is going to be required so we can all go do the same thing and do the right thing, and we aren't at that point yet.

So you can't be unduly critical of the FAA, but, Mr. Chairman, I think it would be in the interests of all concerned if you were to insist periodically that you be assured and all of us be assured that we are in fact working those problems, we are reaching agreements and then we are going to—so that we can get them executed in a timely way.

Mr. CLINGER. Just one other question. We talked sort of around the subject of potential danger of jamming given the terrorist world we live in and DOD's involvement. Is that a real threat in your view, and if so, how palpable is the threat and what can we do about it? Is there any effort being made on the part of the FAA or anybody to really assess that?

Mr. FLEMING. Mr. Clinger, I am not a technical expert in these systems but I am aware of problems as are all of us. I don't view that as a significant issue. I view it as one that has to be dealt with.

In the framework of the way FAA certificates airborne systems and specifically instrument approach systems that are used under very low weather conditions, all potential sources of irregularity or hazard have to be investigated in connection with certification of those systems. When airlines initially implement this capability, for the most part it will be done in airplanes that have inertial navigation capability. That is not true of the Continental commuter airplanes but it is true, of course, with the Northwest 747, the United 767 already equipped, the American 757 which is being equipped as we meet here.

The airplane does not lose its navigation capability if that system is jammed. Two of the first things that would happen on an instrument approach: first the pilot would receive a warning that he has an anomaly because he no longer satisfies the receiver autonomous integrity monitoring requirement that Mr. Poritzky referred to, and furthermore, he is going to get a warning that he probably no longer has an adequate differential GPS signal or GNSS signal from the ground. He is no longer able to complete the instrument approach under that circumstance.

If it happens en route, I don't see it as being a problem for essentially the same reasons. A general aviation user who has a simpler installation in his airplane may have a different sort of a problem, but they don't have to operate generally to the same low weather conditions that airline operators routinely operate.

Perhaps Mr. Brown would be interested in adding a few comments.

Mr. OBERSTAR. Before we do that and I am sure Mr. Beukers is going to add something to that, but I would like to withhold those comments. Mr. Laughlin has a time constraint and I would like to give him the opportunity at this point and then we can, after his question, come back to that matter, because it is important and needs to be further explored.

Mr. LAUGHLIN. Thank you, Mr. Chairman. I wasn't expecting that. I apologize for missing all of today's testimony. I had to be on another committee that was particularly personal to my district so I could not be here. And I am a little reluctant to ask any questions because of missing so much of your testimony, but as I understand what you are talking about here today, it is somewhat similar to what the helicopter pilots were using out in Desert Storm to get around the desert; is that correct?

Mr. PORITZKY. Yes.

Mr. LAUGHLIN. I spent some time out there in active duty with them and they strapped on what looked like a big—not big boy, what is that game? My son has one of them.

Mr. PORITZKY. Game Boy.

Mr. LAUGHLIN. Game Boy. It looked almost the size of a Game Boy with a strap that they put on their thigh. Is this what the helicopters pilots were using or is that a first generation of what you all are talking about, a very simplified mechanism that told them where they were and what altitude?

Mr. BROWN. Mr. Laughlin that is correct. The FAA representatives have a number on display there. They are quite small.

Mr. LAUGHLIN. And yes, that looks real familiar.

My question is, as we develop a system for our commercial and I guess general aviation, is there any thought to anyone sharing the expense of the operation of this system other than the Federal Government?

Mr. BROWN. Mr. Laughlin, I think we all feel like we share in the expense as we pay our taxes and fees into the trust fund or various other mechanisms to the Government. I think you know that FAA's programs were largely user funded, and in addition to that, all of the demonstration programs that we have talked about, some of which you might not have heard about, whether it is ones that we are doing with our organization or individual airlines are undertaking, are all contributed funds from the private sector that we are offering in demonstrating and improving some of the technologies so we make investments in that sense as well.

Mr. LAUGHLIN. I am glad you answered that because my next questions were going to be directed specifically to you, Mr. Brown, because you testified about competitiveness. And as I appreciate this, the first group individuals or companies that we should be interested in are American companies should have taxpayers a part this system that we are relying upon to develop whatever GPS system comes out.

How do we allow the foreign-owned airlines to participate? Do we charge them a fee or just give them a free ride where they can compete against the Continentals, the Northwests, the Americans, the Uniteds, and general aviation companies?

Mr. BROWN. I can't really comment on foreign ownership of airlines. It is not an area of insight or expertise that I have in working with the general aviation community. But on your broader question of the issue of foreign use of the GPS system, I think in a sense you have to look at it as a broader policy goal of the United States in advancing technology that we have and in stimulating the domestic manufacture of specific pieces of equipment that will exploit that technology.

Maybe as you know most of the foreign manufacturers of airframes around the world install U.S. components whether they are engines or avionics or other equipment. The larger we make that market and the more robust our manufacturers, the better off we will be.

Mr. LAUGHLIN. As I understand the testimony here, the systems you are discussing with our committee will have many facets in addition to just telling them where they are on earth and what altitude. I think one of you mentioned the TCAS. It will eliminate the system of that because it will incorporate the same type of anti-collision information for the flight crew.

Mr. PORITZKY. If I could comment on that last point first. Collision avoidance systems are comprised of two elements, the source of information, and the logic it uses to decide whether there is in fact going to be a collision.

That second part is always required but for the first part the GNSS source may be a better and less expensive source of that sensing information of where is the airplane, than the current TCAS uses. It's worth examining.

When the offer was made initially by President Reagan in 1983, it was a humanitarian offer to the world to make the system available at no cost. As Mr. Beukers noted, Admiral Busey's offering elaborated on the initial Presidential offering and the offering the ICAO FANS member made a couple of years later, with a statement that the United States would make the system available at no cost (no additional cost because, as Steve Brown said, we are all paying for it)—for a period of 10 years, plus a number of years of notice. Later the time was made indefinitely with a six-year notice of any change.

The more important point is that in ICAO FANS we were hoping that what was then the Soviet Union, now the Commonwealth of Independent States, would become a reality. When you figure $50 million to $100 million or so per satellite launch, if there are 6, 8, 12 GLONASS satellites, it would of course reduce the total cost to the world of this system.

As Marty Pozesky mentioned this morning, the United States has welcomed, and I know we did in the FANS time, others to provide satellites within that structure to broaden its universality. It would also spread the cost base.

Mr. LAUGHLIN. The last question I have is, having seen firsthand the first generation of the model in the helicopters and the abilities it gave our helicopter pilots, when can we expect the generation of the GPS equipment that you are talking about in this panel today to be on the market, to be available for use? Because it seems to me that engineers can design and test and design and test and come up with all kind of gadgets on the best system and keep improving it, and it never gets out there to the consumer and never is available for the public.

What is some estimate of within some degree of reasonability or probability that we will see a system out here?

Mr. BROWN. Well, depending only how you define the system, let's talk for a moment just about the juicier side of the system and equipment that we as pilots or airlines could buy. That first generation of equipment is out there. Some of the units that you can see here that FAA brought at very economical rates and in the range of $750 to $800 for hand-held units a bit more, but not much for units you can install in an aircraft and look into the electrical system directly. As you will know, those will be enhanced and evolve and become more capable, and we believe that the more capable units will clearly will be available for regular air traffic and air system use by 1995 to 1996. That is why we are so anxious to have FAA participate and be ready to accept this all in that time frame.

Mr. LAUGHLIN. Thank you very much.

Thank you, Mr. Chairman.

And I would just add a word of encouragement to the panel because these are exciting developments and I think it will not only help the pilots figure out where they are but also enhance safety in the air.

Mr. OBERSTAR. I appreciate the gentleman's participation in our hearing and reviewing the technology the gentleman is ultimately a strong supporter of aviation and in his tenure on the committee has become one of our knowledgeable Members, and I appreciate that.

Mr. LAUGHLIN. Thank you, Mr. Chairman.

Mr. OBERSTAR. Can GPS GLONASS and INMARSTAT work together? Is there software available now?

Mr. Beukers, you are the skeptic on this issue, and I want you to answer that and the question Mr. Clinger raised about security.

Mr. BEUKERS. Mr. Chairman, may I just refer to a comment you made previously. I just want to clarify that I am certainly not opposed to GPS being used. I am a very strong proponent of it being used.

Mr. OBERSTAR. I called you a skeptic.

Mr. BEUKERS. I am really anxious to see a parallel program where we address the international system that will materialize 10 to 15 years from now.

On the subject of jamming, I think what we have to address is the fact that the signal that is received from satellites at the end of the runway as we come down to land is extremely weak. It is a very weak signal as opposed to an instrument landing system and it is this difference in the signal levels which makes GPS a vulnerable system.

In addition, the frequency that we are receiving is a single one. The GLONASS system has a different frequency for each satellite and is a much more difficult system to jam.

My suggestion is that we don't dismiss this vulnerability but we properly research it and make sure for our safety people that in fact we have done all we can to satisfy the safety part of the landing process.

On the subject of GLONASS, INMARSTAT and GPS, there are receivers out there today that will receive GLONASS signals, and the GPS signals and process those using all of the satellites that are available and if I may just extend my comment to the GLONASS system itself, GLONASS is a much cheaper system than GPS.

One of the reasons, significant reasons is that the launch capability and the weight of the GLONASS satellites allow three satellites to be launched at the same time. The potential for it being a much less expensive system is there.

One of the problems right now with GLONASS which is being addressed is the componentry on board is not satisfactory for long-term use. In fact, they have a very short life of two to three years mainly because of orbit that they are in and the fact that the spacecraft becomes charged and the components fail.

There is a movement in Europe to have that situation corrected, from Germany to finance some of the reengineering. But yes, sir, GLONASS and GPS can be used together; and as far as INMARSAT is concerned, it has the charter to be the operational entity to operate a GNSS system of the future.

Mr. PORITZKY. To add one word to this.

Mr. OBERSTAR. Mr. Poritzky.

Mr. PORITZKY. On the jamming and interference issue. RTCA, Task Force Two, that Dave Watrous referred to, has a working group, on institutional and transition issues. Just about two weeks ago, a meeting of that group got into the question of vulnerability. The statement that I put into our ACI–NA testimony reflects the views of that group: yes, it is a concern; it had better be a concern.

There are actions that need to be taken. One concern is inadvertent interference, which in the minds of some is the more serious problem, that is, interference inadvertently provided by strong signals on the ground. We urge FAA, FCC, Defense Department, NTIA to work together to assure that those protections, this is the inadvertent jamming and interference, be provided.

At I said in my testimony, I think we agree broadly that RAIM is essential because it provides the fundamental warning. If there is something wrong with the received signal, the "flag" pops up that says "Do not use this information." That is the best protection there is, and I expect everyone on this panel believes it is the most essential protection. But there is significant merit, as our working group found, in having the satellites of both GPS and GLONASS systems up in the sky.

Mr. OBERSTAR. One question just for clarification more than anything else, Mr. Watrous. Page 6 of your testimony, you refer to the technology working group, the institutional group and of the task force, are the former two subdivisions of the task force? What is this structure here? I am not quite clear.

Mr. WATROUS. Mr. Chairman, I have got to catch up with you here. You say page 6.

Mr. OBERSTAR. Page 6 of your testimony: RTCA's task force expects to have a recommendation with the data links associates requested the differential GPS technology within a few weeks, and then you go on to use the technology working group and the institutional group. Are those subdivisions of the task force or separate entities?

Mr. WATROUS. Yes, sir. Let me see if I can't clarify that.

The task force has basically three working groups. One working group is dealing with user needs or requirements. A second working group is dealing with institutional and transition issues. And the third working group is dealing with technology issues.

We have asked technology group to come forward to the full task force with the recommendation as it applies to the differential GPS transmission medium, and that is what we expect to occur probably in the next two to three weeks. Obviously that is a small subset of the total consensus process and the other groups, the operators and the people that are worried about institutional issues will likewise become a part of that process before the entire task force reach as consensus on the recommendation.

Mr. OBERSTAR. Thank you. I understand.

I am going to conclude at this point with this panel. But I am going to express a thought I would like you not necessarily to respond to here. I think the benefits are clearly identified, both current and potential, of GPS. I think the time frame for action clearly is understood by everybody: Last year.

I think that some potential problem areas have been identified in the course of today's testimony—slippages, potential obstacles, potential institutional problem areas, the international framework within which this must take place.

It seems to me—and I am going to make this recommendation to the Secretary of Transportation—we are at a point on GPS the department ought to hold conferences as we did on aging aircraft where all of the players come together in a conference and frankly and straightforwardly and in a spirit of cooperation delineate each one of these areas that needs action fully, agree on a master plan for action and then get to work on implementing it with bench marks for measurement of progress.

It worked well on aging aircraft. It has worked well on other problem areas in this highly complex technological field, it seems to me, and I would like you to just think it over. Don't answer now. I think it is a bad idea to tell me—if you think it is a bad idea, tell me why. But I think that this is one of those milestone opportunities, one of those turning point issues in development that merits the very highest level of participation coordination and interaction by all those participating.

I don't want to come back a year or two from now, two years from now on hearings on authorization of aviation programs and find that a whole sector has slipped, that something we talked about today wasn't done in the intervening two years. I don't want to hear from administrators, airline managers, pilots, air traffic controllers two years from now, If we had only done X, we would be this far ahead.

Now is the time to deal with those problems it seems to me. Now is the time to deal with those opportunities and build on them. And get on with it.

So think it over and give me your thoughts later. And thank you very much for having given so much thought already to so important and complex a technology.

Mr. OBERSTAR. Our next panel is Mr. Howard Johannssen, Professional Airways Systems; and Mr. Will Faville, Director of Safety and Technology for NATCA, National Air Traffic Controllers Association.

TESTIMONY OF HOWARD JOHANNSSEN, PRESIDENT, PROFESSIONAL AIRWAYS SYSTEMS SPECIALISTS, AND WILL FAVILLE, DIRECTOR OF SAFETY AND TECHNOLOGY, NATIONAL AIR TRAFFIC CONTROLLERS ASSOCIATION

Mr. OBERSTAR. Mr. Johannssen, please proceed.

Mr. JOHANNSSEN. I am Howard E. Johannssen, and I am national President and Chairman of the Professional Airways Systems Specialists, PASS, District 6, MEBA AFL-CIO. Thank you for allowing me the opportunity to testify before you today concerning current and future uses of satellite technology in the aviation industry.

Since 1977, PASS has proudly served as the exclusive representative for more than 10,000 Technical and Aviation Systems Specialists employed by the Federal Aviation Administration. Presently, our bargaining unit consists of Flight Standards Aviation Safety Inspectors, Office of Aviation Systems Standards Flight Check Pilots and Crew, and Airway Facilities Systems Specialists who, on a daily basis, install and maintain, repair, inspect and certify all the equipment used in the National Airspace System.

Today, many private and public groups have emerged within the aviation industry which are attempting to expedite replacement of current NAS navigation systems with either a Global Navigation Satellite System, GNSS, or a Global Positioning System, GPS. In fact, in their attempts to obtain support for a rapid GNSS/GPS implementation plan, they advertise that the Department of Defense satellites are nearing operational service and are offered free to the world and that the DOD satellites improve safety, effective traffic separation and precise instrument flight.

Undoubtedly, these groups are motivated foremost by a profit incentive. Yet, after analyzing their actions and their intentions, PASS believes that their goals are honorable and well-directed. Nevertheless, we also firmly argue that safe implementation of the GPS system cannot be accomplished without full agreement by both government and industry on systems standards, procedures and frequency allocations.

To this date, we have not been included in this plan. Therefore, we seek to be included in the GPS planning and implementation process. Unfortunately, today, I didn't hear much about frequency allocation. And, if you were on a GPS approach to O'Hare, and are a rock and roll fan and listen to DC–101 in Chicago, you couldn't use GPS because of the frequency problems. And that is just the very simple, basic concept that needs to be addressed.

Currently, the FAA, in conjunction with aviation groups, is sponsoring a proof-of-concept approach for dealing with experimental GPS systems. Once this approach is tested and verified, we believe that many short and long-term benefits can be achieved.

Under investigation now is a GNSS In-service Test, GIST, an FAA-sponsored project called project DFW(1)(PD), which is being conducted at the Dallas and Alliance Airports. According to its stated purpose, this project will provide for the demonstration of a Global Navigation Satellite System with the capability of performing precision approaches and landings.

While this project appears to ambitiously cover all aspects of precision approaches, data is only being gathered on Category I approaches, the use of Differential GPS and a follow-up for 3 Dimensional technology. Hence, while the data may appear to fulfill expectations, many challenges could arise since Category II and Category III operations may pose technical difficulties which are significantly different from those in Category I.

To date, some problems have already arisen in this procedure and in other planning projects conducted by the FAA. In fact, until recently, the FAA's technical work force—our Airways Facilities employees and its managers—had been entirely excluded from the GPS planning and testing process. Yet, the Agency's internal documentation states, and I quote: "Augmentation of GPS may require the expenditure of funds for additional space and/or ground stations and may require publicly funded differential stations. If so, these facilities will have to be sponsored and procured by Airways Facilities."

Without a doubt, Project DFW is extremely promising and a highly valuable project. However, PASS believes that our Systems Specialists must be allowed to participate in every aspect of this project and must be given the opportunity to assist in the determination of safe parameters for the GPS in private and commercial aviation.

Therefore, we urge the FAA to include all facets of the aviation community in this initial test project and to provide the necessary resources for full exploration of the GPS beyond military and general aviation operations.

Unquestionably, our members have the talent, knowledge and ability necessary to maintain our current systems and to install, maintain and certify future systems within the FAA. Additionally, our Flights Standards and Aviation Systems Standards members have the regulatory and avionics experience required for the successful completion of testing and procedures for GPS.

As you can see, development of these procedures and equipments for satellite-based systems should incorporate representations from all disciplines within the FAA.

Through our affiliation with many international aviation organizations, including the International Transportation Federation, ITF, Public Services International, PSI—and I would add that between those groups they represent 25 million workers around this world—and IFATSEA, the International Federation of Air Traffic Safety Electronics Associations, PASS has become aware of many international concerns that pertain to the implementation of the GPS system.

From my discussions with representatives of these organizations, which represent ATC professionals, safety inspectors and pilots abroad, I have found a mixed spectrum of fears, particularly with regard to use of a GPS system that would rely on the current U.S. DOD satellite system.

In our opinion, without the International Civil Aviation Organization, ICAO, approval for the use of U.S. GPS satellite navigation, the FAA will be required to operate dual facilities—ground equipment and satellites—at all U.S. international airports. Therefore, there is an urgency for full international agreement and cooperation on the use of GPS. Undoubtedly, without international support, implementation of a GPS system would be very costly and would require an enormous amount of equipment and personnel.

In closing, as we prepare to rely more and more upon satellite technology, our primary focus must remain on the FAA and the way it will do business in the future. At present, the FAA services the users of the NAS in a remarkable way. In our opinion, there is no other Federal agency that can compare to FAA's record or level of accomplishment. The mission of the FAA is carried out safely and efficiently because the people and the equipment are proven.

Thus, in order to preserve its solid reputation, as well as the integrity of the flying skies, the FAA must strive to achieve the cooperation and the concerted efforts of the entire aviation community, for only with substantial teamwork will the FAA be able to ensure the safety of the National Airspace System as we embark upon future navigation systems.

Thank you.

Mr. OBERSTAR. Thank you very much. I appreciate your comments, and I will have some questions later.

Mr. Faville.

Mr. FAVILLE. Thank you.

Good afternoon, Mr. Chairman and Members of the subcommittee. My name is Will Faville, and I am the Director of Safety and Technology for the National Air Traffic Controllers Association. NATCA is the exclusive representative of this Nation's 14,700 air traffic controllers employed by the FAA.

I want to thank you, Chairman Oberstar, for having this hearing today. The Global Positioning System is a technology that will change the face of aviation in the United States and throughout the world. Its applications are limitless. We could have radar-like presentations for all parts of the world. Cost would be much less than some current technologies under consideration at the FAA.

Last month, we appeared before this body to recommend ways the FAA could do more with less. One of our recommendations was to fully accept the new technology of GPS and to stop throwing good money at Precision Runway Monitoring, PRM, Microwave Landing System and Oceanic Display and Planning Systems, ODAPS. We believe that GPS could replace all the named systems with a more precise and cost-efficient system.

PRM is a system that will be obsolete before it becomes fully operational. The first operational model just went into the Raleigh-Durham Airport. Unfortunately, the FAA is considering a replacement model for the equipment at Raleigh next year.

As we mentioned last month, the initial desire for MLS in the late 1960s and early 1970s was well founded. However, since that time, many of the deficiencies of the ILS have been resolved. The MLS remains a very costly replacement. The cost is not only experienced by the FAA, but is felt by the airlines as they retrofit their aircraft for MLS ability. Utilizing GPS technology will provide the user with a more cost-effective, true precision approach.

Mr. Chairman, you are well aware of the delay and rising costs involved with FAA's attempt to bring a fully functional and reliable ODAPS to life. What started out as a 36-month, $22 million project has escalated into a 100-month, $51 million project, and the end is still nowhere in sight.

I believe we heard Secretary Pena say the uses of GPS will bring about greater enhancements in the oceanic en route controlling. Yet the ODAPS, as it currently stands, cannot support ADS the information that could be provided through the GPS/GNSS systems.

We believe it is a terrible platform to be putting into the FAA in our en route centers at this time.

These are but a few of the projects that should be terminated. Monies appropriated by the Congress and the personnel delegated by the FAA to these projects should now be invested in the GPS before we lose any of our competitive edge we may gain.

I know that the FAA testified earlier that it is fully committed to GPS. Unfortunately, its actions are not keeping pace with its words. The FAA's air traffic GPS office, the one that helps put together the procedures that need to be done to implement GPS, is currently staffed by two people full time. There are two other temporary details, but they are tasked with the responsibility of developing the FAA's internal training system for GPS. Recently, an additional two full-time positions have been authorized, but they have yet to be filled.

FAA regions are in worse shape. Each region has an individual assigned to GPS, but this is as an additional duty, and they have many other duties that are assigned to them already keeping them from full-time participation and work on GPS. The FAA must fully staff these available positions and seek to increase its staffing in the GPS area. Without the proper support, the FAA's effort will be a Band-Aid approach, with the pilots and controllers being left outside the loop.

I believe you asked Marty Pozesky how to go a little bit faster in implementing. He mentioned the SOIT, the Satellite Operational Implementation Time. We haven't seen any air traffic involvement, with FAA seeming to be involved in all the different areas in air traffic. And those are the procedures that were addressed by the previous committee that need to be implemented and put together to develop a good system of the road map. I believe, Mr. Chairman, you referred to it as a good, vital road map that will lead us into the future implementation.

And I believe I may have heard Mr. Broderick misspeak when he mentioned there were several air traffic controllers involved. As far as we know, there has not been one air traffic controller involved with any of the GPS investigations. And we believe that is crucial to the proper success and building of the road map into the future of GPS.

Air traffic controllers across the Nation do not know anything of the FAA's plans in regards to GPS. Apparently, the GPS office in Washington developed a controller briefing package and sent it to the field months ago, but, to date, very few controllers have been briefed. Those few controllers who know of GPS happened to be private pilots and gathered information from other non-FAA organizations.

The FAA plans to test several applications for GPS at various anticipates throughout the U.S. by the fall of this year. Testing is to be conducted at the Oshkosh Air Show, at Dallas and Juneau, Alaska. Air traffic controllers at those facilities have, again, been frozen out of the loop. This cannot be allowed to condition.

GPS can be a valuable technology for the FAA and our Nation's troubled airlines and aviation system; but, meaningful controller involvement is a must.

All too often, controller involvement is grudgingly permitted by the FAA. We witnessed this with TCAS and the Advanced Automation System, to name a few of the occasions. The FAA must understand that the air traffic controllers and their input into new technology are a very valuable resource available to them. NATCA firmly believed that a NATCA liaison office should be associated with the air traffic GPS office at FAA headquarters, which is similar to a project we attempted to set up with FAA under AAS which is now starting to come to fruition.

The road map for implementation can only be completed with good input from all those line people and the final operators of the system to develop the correct procedures and to fully utilize the procedures of the system.

Thank you, Mr. Chairman. I will be glad to answer any questions you or the subcommittee may have.

Mr. OBERSTAR. I must say I am very disappointed and distressed to hear that—from your statements—the FAA has not been inclusive of either professional airway systems specialists our air traffic controllers. And yet, we heard the testimony this morning, Mr. Broderick saying they have been included. They have been consulted.

And your perspective is that a packet of information was sent out. Maybe some first-line supervisors were involved in the discussions. They are air traffic controllers, not full time. But there certainly is a misperception on FAA's part, if the reality from the controller's side is we haven't been consulted. Somebody at the top has been told that you have been. And you are saying you haven't. And that is a mistake.

If that is the case, it is certainly shortchanging the opportunities for progress here to fail to include those who would be most intimately associated with Global Positioning System, along with pilots, in the operation of such a system.

There have been some suggestions that FAA should be procured and owned and operated by airports and airlines because they can do it faster and cheaper and they won't have all the government hoops to jump through. Do you think it would be quicker, cheaper? And would the end result be better than proceeding in the way that FAA is doing?

Mr. FAVILLE. Firstly, Mr. Chairman, I believe that Mr. Poritzky talked about there is some bureaucracy that comes together when trying to develop and come up with any of the systems. I believe that it was mentioned earlier there wasn't one FAA—we have flight standards, the R&D and the air traffic and the Airways Facilities in use in implementing everything.

I was very pleased to hear the suggestion that you had made just at the end of the last panel on getting all the groups together as long as we remember that part of those groups are line controllers, the line pilots, the line Systems Specialists that are involved in putting the information together. I would hate to see them left out of the loop, no matter which entity were to work on a quick implementation of the GPS.

Mr. OBERSTAR. Controllers and PASS members were included in my description of who ought to participate in such a summit.

Mr. FAVILLE. I understand that, sir.

Mr. OBERSTAR. The users and the operators.

Mr. FAVILLE. I certainly hope we have others that would understand the same, sir.

Mr. JOHANNSSEN. In response to your question as well, in previous testimony here and in appropriations, the GAO has taken a hard look at FAA and the way they go about their business, and there is no question that the current employees of the FAA do a far better job, in a quicker period of time, cheaper than any contractor or any group of contractors. The number that I remember that came out of the study was a difference of about $45,000 per employee cheaper done in-house than out of-house. And the GAO has those numbers, and I believe I left those with my last testimony.

But the question really doesn't go, I think so much—the question we have about what is going on with the system is we are ready to get on with it. We embrace change.

Historically, unions have been perceived as featherbedding and whatever else. With change and automation, jobs are lost and opportunities are lost. That is not the case in technology. For every job we are able to displace and find a better way to do it, generally we create another one. Maybe not right in house but out in some factory some place developing electronic equipment or whatever else.

So we are ready to go with GPS and work hard on it. But all we ask is to be included. We believe that we have something to offer.

Mr. OBERSTAR. Thank you very much. I have a couple of other questions that I will come back to later.

Mr. Clinger.

Mr. CLINGER. Thank you, Mr. Chairman.

It seems to me that this has been a chronic situation with regard to the involvement of the professional air traffic controllers and the airway specialists in discussions of new systems. Is that an erroneous perception? I think that perhaps you testified or somebody testified that in developing TCAS there was an exclusion of your organization.

Mr. JOHANNSSEN. FAA is undergoing a cultural change. And a culture doesn't change overnight. In Airways Facilities, and starting in Flight Standards we are working together. There is a real collaborative effort.

But other segments of the FAA who are not used to working directly with the union or organized workers still go about business their own way, and I don't view it as an intentional piece on their part. They need to be brought into this process called cultural change where we draw from the people who work for us all the resources and all the information so that we come out with something that is good for everybody.

So I don't take it personal. And I don't think it is purposeful. It is just that they are used to doing business the old way, and they need to hear me say this here. It will get back to them, and they will consider doing things differently.

Mr. CLINGER. We are talking about from a management point of view, FAA's management point of view. Let me ask you this. What kind of stress is it going to put on the system to transfer, to have your members assigned to GPS or GNSS development?

Mr. JOHANNSSEN. It is stress, as I have testified before. We are short about 3,000 people. And any time you take a person to do something else, you are stressing the system.

Mr. CLINGER. So it will be impacted.

Mr. JOHANNSSEN. It does stress the system. However, it also stresses the system more not to be involved. So there is a little robbing Peter to pay Paul, balancing the stress of the system. But we are not so terribly short that we couldn't have some involvement on my part and some others.

Mr. FAVILLE. Absolutely. I think we would welcome the participation because what we have found on the air traffic end is that we will have new procedures implemented, TCAS being a prime example, without the line control involvement where those that have not controlled traffic for years are saying that this is the best way to control the traffic, and the men and women working day to day know the best ways to control traffic and the way to set it up so that they can more efficiently and safely move air traffic.

Mr. CLINGER. One place that you diverge dramatically from earlier testimony, I gather what you are saying is that you would propose to stop all funding from MLS, for example, and existing land-based systems and put that funding into GPS with the idea of expediting that. Were you here when Mr. Broderick testified that we needed both of those systems? We needed to go forth with both of those systems to ensure that we would have a sort of a seamless safety regimen out there.

Mr. FAVILLE. I think one of the best examples is the oceanic displays as Secretary Pena, Marty Pozesky and everybody has mentioned, the increase in en route oceanic air traffic control. Currently, we are using strips, the old-fashioned ways. A new project was developed. ODAPS, Oceanic Display and Planning Systems, is now in New York center and Oakland center to assist.

However, it is not working the way it needs to be worked. Several pieces of the system are working well. So that, instead of throwing more money into this project trying to fix this project, let's freeze the funding for this project. Let's let it sit as is. Move those people that are now working at headquarters—and we have had a recent commitment from FAA to get line controller involvement—those that are using the system and develop another system.

ODAPS is an example that was displayed as a system that would support GPS information and data link through the use of ADS, Automated Dependant surveillance. We find that disturbing that we are going to continue on funding ODAPS when the money could be spent, we feel, more wisely.

The same is true with the precision runway monitoring equipment. GNSS is down the road another four or five years. We are currently funding a radar system that is part of the system, the E scan radar, when they update it and bring in the whole new system. Yet with the E scan, precision runway monitoring information, the closest at Raleigh-Durham that we are able to get the aircraft on parallel approach is 3,400 feet. We believe with GPS technology we will be able to bring that down to 2,900 feet with more accuracy and much more accurate display and information to the controllers and feedback to the pilots.

Mr. CLINGER. Thank you, gentlemen.

Mr. OBERSTAR. I just want one clarification on project DFW. Could you describe that?

Mr. JOHANNSSEN. I understand that—I have not seen it, so I am only giving you what has been passed to me in papers that I have read. They currently have a project in place checking GPS approaches for Category I's out in Dallas. The equipment is there. It is ongoing. And I understand it has been pretty successful from what I hear. I would be afraid to tell you any more because I would be grasping stuff. It wouldn't be fair to you.

Mr. OBERSTAR. Thank you.

The final question on the international aspect that we heard testimony previously of at least one witness who felt that the United States ought to allow the international system—whether it is the Russian system or the one being developed by the European Community—to either catch up with us or to be integrated with our system. What do you hear from your counterparts in air traffic control in Europe or elsewhere about Global Positioning System and governments that are under way in the European Community and within Russia?

Mr. FAVILLE. Most recently, Mr. Chairman—not most recently—last April, I was at an International Federation of Air Traffic Controllers Association meeting, and discussions of GPS was brought up. Their concerns are those that are still expressed by the aviation community. Their lack of information and knowledge on the systems, other than what they are hearing from their civil aviation authorities on the concern that what happens when the U.S. turn its off, the fear of terrorism.

There wasn't enough information for them to start formulating our trying to work on what was going to happen in the future. They are part of the FANS, and they are trying to work with the information that comes from that. They are working on the Automatic Dependant Surveillance, ADS. They would like to see more of this information—controllers worldwide.

We are short staffing. We are short good, reliable equipment and modern technological equipment.

Mr. JOHANNSSEN. Mr. Chairman, I just came back from Asia. I was in China and in Thailand. In Thailand, I was selected by the International Federation of Air Traffic Safety Electronic Associations to be the rep to ICAO for member countries. I was the individual who brought Russia into the international organization last year in Cypress, and I have spent the last 12 years working with foreign countries in exactly what we do here.

Back in March of this year I was selected by the ITF, the International Transportation Federation, representing some 10 million workers and PSI, some 25 million workers, as their rep to ICAO. So I can sit before you and say that I speak for the rest of the unions for air traffic services around the entire world. They elected me to do that.

Mr. OBERSTAR. That is incredible. It is a compliment to you.

Mr. JOHANNSSEN. Thank you. I appreciate it. And I will be representing those people at ICAO.

What I have learned is this—and very, very similar to Will's findings—that the people who maintain the equipment, up through the managerial levels, really don't get the knowledge and information about GPS, as I think they should receive that information, to be forceful enough in their own countries to take another look to change the views at ICAO. I think what we are stuck with is a group of well-meaning, hard-working folks at ICAO who came with certain knowledge and skills and abilities some time ago, and they still dwell in those thoughts and those feelings without going back and really, providing information to the people that could help them and checking it out and perhaps consider changing their position.

In the first week of September I am hosting an international convention in Orlando where, hopefully, there will be 50 countries, and I have invited these nice gentlemen with this equipment to bring it down, and we will be able to educate 50 nations in the world about GPS, and, hopefully, that will go a long way in acceptance. I think that is what it is.

GPS is viewed as the Americans once again forcing our technology down their throat. There is a lot of pride about developing their own. I think they misunderstand that, and they get it confused with MLS. That GPS replaces MLS, and they can't have their MLS, and that is not the case. We can have a GPS system and MLS if we choose, Cat II's and III's can have MLS. And they can take advantage of the GPS when they need it in traveling around.

You look at Europe with 26 air traffic control facilities and the new European Community. They can't decide what to open or close or maybe leave the same. We need to take a stance of being helpful and informative and not be seen as an aggressor in our technology but a sharer in our technology. And I think we will do just fine.

Mr. OBERSTAR. Thank you very, very much.

It seems to me in Europe, with all the military air space reservations, that GPS would be very, very valuable in maneuvering aircraft and particularly in the new areas—new air space added with East Germany moving into union with West Germany. And the former Warsaw pact states that are independent nations have added tremendous amount of air space in Europe to air navigation, albeit not heavily utilized. But there is a whole fresh field of application of this technology that could be most useful.

Mr. JOHANNSSEN. And it is so expansive that we can only begin to perceive 5 or 10 percent of what we will see 10, 15, 20 years from now, and I think that is going to be wonderful for our economy.

Mr. OBERSTAR. Thank you very, very much for your presentation today.

Our final panel for the day includes Mr. David Mineck, Director of Advanced Systems, Collins Commercial Avionics, speaking for the General Aviation Manufacturers Association; Mr. Ralph Eschenbach, Vice President of Navigation Division, Trimble Navigation; and Mr. Chris McCleary, Vice President, Sales and Marketing, American Mobile Satellite Corporation.

TESTIMONY OF DAVID MINECK, DIRECTOR OF ADVANCED SYSTEMS, COLLINS COMMERCIAL AVIONICS, ON BEHALF OF THE GENERAL AVIATION MANUFACTURERS ASSOCIATION; RALPH ESCHENBACH, VICE PRESIDENT, NAVIGATION DIVISION, TRIMBLE NAVIGATION, INC.; AND CHRIS MCCLEARY, VICE PRESIDENT, SALES AND MARKETING, AMERICAN MOBILE SATELLITE CORPORATION

Mr. OBERSTAR. Mr. Mineck, welcome. Glad to have you.

Mr. MINECK. Thank you.

As you kindly introduced me, I am with the Collins Avionics part of Rockwell. I am here speaking for GAMA and Collins Commercial Avionics.

I have submitted a written statement and, in light of the hour, I will try to be brief in summarizing my comments.

GAMA represents United States' companies that manufacture business, commuter, personal aircraft, engines, avionics and other components. They have been very involved in the air navigation policies over the years, and they have been involved in numerous satellite navigation task forces and working groups.

On behalf of GAMA, I would like to iterate we are a very strong proponent of the Global Positioning System and the satellite-based navigation systems.

Collins Avionics is based in Cedar Rapids, Iowa, and we manufacture a complete line of communication, navigation and flight control avionics systems for all pieces of the aviation business—general aviation, airline and military aircraft. Our parent company has been heavily involved in the original development of the GPS satellites and, of course, has built the satellites that are currently in space. We provided the majority of the GPS systems involved in the DOD departments, and we have been heavily involved as a supplier of commercial GPS for the consumer marketplace, including a lot of the general aviation market that is currently out there today. We are also involved in manufacturing equipment for land transportation, both railroads and the trucks.

And while, as we saw from Mr. Ferguson's presentation today, we are going to eliminate a lot of the products that we currently supply, on behalf of Collins I would like to reiterate that we are a strong backer of the Global Positioning System and the activities that are going on in that area.

As our customers across the board have already installed GPS equipment, we believe that the industry impact, as has been said today, is probably as big as anything that has happened in the last 30 or 40 years. Many of our customers are likening it to the change that we had in the transportation industry department when the turbofan engine was introduced.

So the real question is not do we do GPS, but, as we heard in the last few hours, how and how do we get on with it quickly?

I would like to touch briefly on some of the benefits. We have discussed most of them today, but I think there is one aspect that has not had enough attention as we have chatted today and that is the benefits for safety and operation.

We have talked a lot about cost savings, but particularly in the general aviation piece of the marketplace the ability to have precision approach guidance at literally thousands of airports around the world is extremely important. There is another aspect of that technology also there. To combine with simple databases we can have a substantial improvement in giving the pilot awareness of the terrain around him.

One of the biggest causes of fatalities in the aviation business today is controlled flight into terrain. We hit things when we are not planning on it. With GPS we can make marvelous steps forward in improving that. And if we add a data link, as we discussed today, we can communicate better and create TCAS–4 systems for much less money than what the current TCAS systems cost. It will allow everybody to have awareness of who is flying around them, which will be a big step forward to task avoidance and separation.

We have talked a lot about the benefits and approach procedures. I would like to reiterate from our viewpoint that we do feel that the development of the approach procedures, and the associated air traffic control procedures to go with it, is lagging from some of the technology that we have been developing.

I think another aspect that we feel that there is work needed in is also in the area of integration from the pilot's viewpoint into the cockpit. We have got some marvelous technology in front of us, and we have a lot of systems out there today. Mr. Ferguson talked about very quick payback of systems as he integrated them into his airplane.

As we develop our operational definitions and procedures, we have to be careful that we don't create requirements to go change all that equipment that is currently in the airplanes today. Because, while software is wonderful, it is also expensive to change, and we have to have an organized plan so that we don't change this two or three times over the next few years as we go forward.

I would like to commend the FAA for all of the work that they have done in really trying to get this going. They have done things a lot faster than we have seen in the past. There has been a number of demonstration programs that we have heard about today that are developing, a lot of operational concepts as well as the technology. They have also brought in other nations.

One area that wasn't mentioned today that I think is significant that the FAA has supported and that is in the Fiji islands they are developing a complete GPS-based navigation and air traffic management system as a pilot program. And, basically, they have four NAV aids throughout many, many thousands of islands and thousands of square miles of area.

And so this is a turnkey approach as to how to build an air traffic management system around GPS. That is in process today. It is significant in terms of what GPS-based systems can do for the world in those areas that don't have a system today. It is not our problem in the U.S., but it certainly is in a lot of places in the world. And I want to commend the FAA for supporting that activity.

I think—to go on to the issues to be resolved quickly. They have been covered thoroughly today.

We would reinforce that, right now, we are too fragmented as to how we are going about this. In the FAA there is not a central plan. We have heard that several times. As a member of the industry, we try to actively participate in the committees that we have heard about, RTCA, IATA, all the other groups that are working.

But, as a simple example of what we are facing in the industry on the very issue of data links visual communications to and from the airplanes, there are approximately 40 industry committees on a worldwide basis. We heard six different kinds of definitions this morning. My engineers gave me something on the order of 15. We only need one or two. We don't have a crisp way of saying let's pick these two and let's go forward.

I think that we have heard the mandate that we need an implementation plan that maybe is a little bit more crisp in its time scale. The users around the world are looking for the benefits. The world's transportation industry has a lot of financial problems, and the kinds of cost savings that we have heard about today are just the tip of the iceberg.

One of the major U.S. airlines just recently quoted if they could save one minute per flight on their 747–400, they would save $100 million a year in fuel. So the kinds of cost savings that we were looking at on the models here are available and available immediately, but we have to get the traffic procedures in place to support them.

We have covered the integrity warning issue thoroughly today. That is a key factor that needs to be addressed. I think the area of operational integration is another one, not only from the cockpit viewpoint but from as we heard the air traffic controllers and the operators.

About 15 years ago, the industry spent a lot of money putting what they call flight management systems into all the new airplanes in the world, and those first started hitting the industry in 1978, 1979. Boeing pioneered a lot of it in the early 1980s. Just today we are beginning to see the operational benefits that those flight management systems have had in the airplanes in the last 10 years, and that is because we are finally getting some of the things that we looked at where we can do the direct routes and preferential routes. The equipment and technology have been there for quite a while. We as a group haven't kept the operational aspects in sync.

I think the other point that I would like to make in closing is we have talked a lot about cost allocation today, and certainly, from the general aviation viewpoint, we feel we are contributing to the user fees. It would be difficult to allocate on a per-use basis anything like using GPS or differential GPS fees. And, in particular, there is a concern that when we have things that really do provide safety, they shouldn't be financed on an as-you-fly basis because, in reality, we may end up deferring people from using them when they do, in fact, enhance safety.

So, in conclusion, I would like to reemphasize that we feel strongly that the U.S. is in the position to lead the transition to Global Positioning System. We have a lot of issues to deal with in terms of control and the things we have heard about the European attitudes.

We have heard from our major European operators, the regionals, corporates, airlines, the same types of concerns and the same types of immediate cost benefits that they see. They are frustrated with their own infrastructure and being able to implement it. I feel—and this is really a Collins position more than a GAMA—that we have an opportunity in the U.S. to show the world what it will do, and the world will tend to follow. Whether it is our technology or somebody else's, we need to solve the airline's problems.

I greatly appreciate this opportunity to be here today and will be happy to answer any questions that you might ask. Thank you.

Mr. OBERSTAR. Thank you very much Mr. Mineck. You covered a lot of information in a very short period of time. It is wonderful.

Mr. ESCHENBACH. Well pronounced. Thank you very much, Mr. Chairman. And thank you for inviting us to participate in this subcommittee.

I am Ralph Eschenbach, Vice President of Navigation and General Manager of the Navigation Division at Trimble, and I am speaking not only as a representative of Trimble but as a pilot. I have been flying for 25 years myself, and there was a time that I claimed that I had more GPS hours than any other pilot. But I have been passed in the last two years.

GPS will revolutionize the aviation industry, but it is important to recognize that this is just one of the industries that GPS is revolutionizing along the way. Current estimates are that aviation will be 3 percent of the users of GPS when it fully implemented into the system.

The reason that this has been so revolutionary in aviation is that there is great economic convenience and safety benefits. I wish Mr. McLaughlin were here to realize that we are not talking about the future of air navigation, we are talking about the present of it. Trimble has already shipped well over 20,000 GPS receivers to aviation owners and pilots. And this is a system that is getting utilized today, even though many of the operational procedures are lagging, as we have heard from quite a bit of testimony.

Today, I will just address four of the major areas that GPS will have impact in, and you have heard about a lot of them: navigation, collision avoidance, landing and surveillance. And I hope to add a little bit to each one of those.

In the navigation area, GPS, as we heard from Mr. Ferguson this morning, offers us tremendous savings. He talked about return on investment in 91 days. What he didn't mention is that is only on their routes between Houston and Florida. Right there he is saving the system costs in 91 days. If he could use it in the entire system, it would be closer to 91 minutes. So the savings is just huge for the airlines.

But, again, the procedures need to be there, and at this point they are still lacking.

In the area of collision avoidance, right now we are starting to implement and have implemented the TCAS system. We heard talk about TCAS-4 coming on line. I endorse that wholeheartedly. I am afraid if we don't we will be sitting here five years from now talking about TCAS the same way we talk about MLS. It will be the MLS of the collision avoidance system if we don't get moving.

And the problem is not MLS our TCAS. The problem is the length of time that it takes a good idea to get implemented into the system.

The third area is, obviously, landing systems and landing aircraft. You have seen equipment on the table over here that demonstrates that that is available today. Landing capability could be put into the airports around the country and give us about a four to fivefold increase in the ability to land aircraft at smaller airports, reducing congestion and reducing aircraft density.

Lastly, we have talked with the area of surveillance and ADS. This is also an area where GPS will become a prime player. This will greatly reduce the separation that we need in the transoceanic corridors. Also, we will be able to start talking about GPS handling the runway incursion problems on the ground, which is also a surveillance kind of issue.

It is well-known that the accident that happened in San Diego was caused by human error, and if we can get GPS into runway incursion situations, it can eliminate those kinds of problems.

I would like to cover a couple of things that I think we have been talking about today.

We have talked about the jamming issue. I think the jamming issue will become a moot point as we get further down the stream. As Mr. Pozesky stated earlier in the testimony, the GPS jam is fail-safe; i.e., if it does jam, it will not give you an erroneous position solution.

And, in fact, if you want to be devious, the ILS is much easier to spoof to lead an aircraft astray than GPS and so is GLONASS easier to spoof. Because it has, as Mr. Beukers pointed out, satellites on a single frequency. So all you have to do is mislead one satellite, and it is easier to do than with GPS.

Mr. OBERSTAR. You said that it would not mislead you, it would just not provide you information? Is that what you mean?

Mr. ESCHENBACH. GPS will fail-safe. If it is jammed, it will realize that it is not getting a solution, and it will put up a display saying, don't do a landing. Abort the landing at this time. Whereas, with the MLS, it would be easier for a terrorist to build an ILS spoofer to lead the aircraft into the ground someplace else without the aircraft knowing that it was on an erroneous signal. GPS is fail-safe in that manner.

Another issue on the integrity side. If we want integrity, we have heard people talk about adding GLONASS. The real issue is to add six more GPS satellites. That would completely eliminate the integrity problem as an issue.

Lastly, I quote Aviation Daily. They said that GPS will save the FAA millions of dollars. I would amend that and say it would be hundreds of millions of dollars. The only question is when.

We have had, I think in the last two years, a dramatic turnaround in the position of the FAA and the support of the FAA. I have been with GPS for 15 years, and in the first 13 of those it was like pushing a rope. But the position and attitude of FAA in the last two years with both Mr. Pozesky and Mr. Broderick and the satellite program office with Joe Dorfler, has been supportive and we have been getting very good support from them.

On the last point, I would like to comment about the issue of funding.

There has been a lot of questions about where the funding is going to come from. There are huge FAA savings. You saw the rack of equipment that Mr. Ferguson had. Behind each one of those black boxes is an FAA department to make sure that it works right, it is tested right, it is certified right. And, by bringing in GPS, there will be huge FAA savings. He was generous in offering the industry to pay for the cost of the GPS, the $300 million to $500 million a year.

I would like to point out that the aviation industry will be a 3 percent user of GPS, and so there is a lot of other benefits that need to be looked at. And by taxing the U.S. industry you put the U.S. industry at a disadvantage vis-a-vis the foreign carrier. So that is really not the right solution in the long term. We ought to look for cost savings rather than revenue generation.

If we can move up the GPS decision a year, we will save far more than the cost for a year. We need to treat GPS as a utility—an information utility for the nation. We need to take advantage of this utility while we have the lead and not wait for international organizations to catch up. We need, with our leadership in that, to take advantage of it and do it now. The pressure needs to be maintained.

So I will entertain any questions when the time is appropriate, Mr. Chairman.

Mr. OBERSTAR. Thank you very much.

Mr. MCCLEARY. Mr. Chairman and Members of the subcommittee, my name is Chris McCleary. I am Vice President of Marketing and Sales for American Mobile Satellite Corporation, and we are honored to be part of this process today.

And I can also say that we are honored to be a part of a panel with two what we think are world-class manufacturers, Collins and Trimble.

Unlike earlier subject material presented today, we are here to explain a new commercial satellite project that will benefit the aeronautical industry. The AMSC satellite system will provide satellite-delivered voice and data communications, in some cases complementary to GPS, but, more to the point, to extend capacity and functionality to the airline industry.

AMSC is the entity licensed by the Federal Communications Commission. We received our license in 1989. We are licensed to construct and launch and operate a mobile satellite service for the United States. We are authorized to launch three geostationary satellites, and next year we will launch our first satellite as part of that system.

The FCC authorization specifically includes permission for us to provide aeronautical services and the provision of aeronautical safety services as part of our license.

AMSC's owners include—and it is quite a group—GM/Hughes Electronics, General Dynamics, McCaw Cellular Communications, LIN Broadcasting, MTEL and others, and to date we have raised and funded $375 million towards the half a billion dollar commercial project.

It is interesting to note that all of these companies except General Dynamics initially submitted an application for the sole license, and the FCC wanted to speed the process to bring the services to the public and therefore created a consortium. And we have benefited from the synergies from these fine companies; our owners.

When our satellites launch, we will have over 2,000 voice channels covering North America to provide mobile communication services to land, mobile, maritime and land aeronautical users. In addition to these uses, we are also licensed to provide regular phone service to those remote rural areas that are unable to secure wired phone service.

Now, in addition to providing aeronautical services, we are going to provide vital communication services to public safety, fire, police and ambulance services in remote areas. We are already working with the FBI and DEA to provide these services. We will service the interstate transportation industry with seamless voice communication for trucks, barges, commercial ships, all freight, all traveling within North America.

Although our license is for the United States and our protectorates, our technical coverage is the entire continent of North America. This half a billion dollar project is strengthening the American economy.

We have selected Hughes Aircraft Company to manufacture the $125 million satellite. General Dynamics is providing launch services. And Westinghouse Electronic Systems, a world leader in air traffic systems, will build our ground services, avionics and mobile telephone systems.

Upon the launch and deployment of the AMSC system, the aeronautical industry will benefit. We will be able to provide ATC, APC, AAC, AOC and air passenger communications to both air freight, ATA fleets, as well as to general aviation.

The AAC and APC services will be provided immediately upon launch through our standard ground segment facilities and avionics being constructed by our business partner, Westinghouse. ATC and AOC services and safety services, however, will require specialized ground segment facilities, and we are currently working with existing service providers such as IDB Aeronautical and ARINC to develop these specialized facilities.

We have also a very special product that we are going to be bringing to the individual airlines. We have the capability of providing individual airlines with private networks—private voice and data networks—using satellite-based technology.

Mr. McCLEARY. Pursuant to our FCC requirement of our license we are also obligated and we assume the responsibility for providing preemptive access for all area nautical users for this shared satellite system. We will reserve pools of channels for those services and draw upon those channels as needed.

This creates the ability to share a very expensive satellite system for multiple uses yet allowing the areanautical community to be assured that the satellite service provider in the U.S. provides priority and preemptive access.

So in closing we are extremely enthusiastic about being the U.S. provider of satellite services for the areanautical community and we know that towards the end of the century, satellites can play a major role in providing cost-effective additional capacity and functionality to the U.S. areanautical industry and thank you very much.

Mr. OBERSTAR. Thank you very much Mr. McCleary for your testimony and which I read prior to your presentation and which certainly underscores the significance of the technology and the importance to aviation and to users.

Mr. OBERSTAR. I am concerned that we have heard again and again that there is no master plan developed by FAA, at least no perceived master plan on the part of users, manufacturers, system operators, air traffic controllers and the FAA said we do have a master plan, we are proceeding with it. And yet the perception is there isn't one.

It seems to me that we need to understand the terms and understand each and perhaps bringing, as I have suggested earlier, bringing all of the participants, everybody who has anything to do with global positioning satellites together in a single conference and in getting these matters resolved would be very important to the future of this system, and make sure that everyone is singing from the same hymn book or reading from the same page, however you want to describe it.

Mr. Mineck, your advice is don't keep changing the software. It is very costly and there is always this temptation, you know, Mr. Clinger and I have been sitting on committees together for the past 11 years. Before that, on economic development issues, but aviation technology issues, particularly the last 11 years, again and whether it is the manufacturers, the users, the air traffic controllers, whatever the technology is, technology in this field is so exciting and developed so rapidly and has so many potentials, once it is developed, that everybody has a new bell or whistle, tweeter, or woofer that they want to add to it, and we have heard this again and again, well it is great to have it in black and white, can't you put it in color.

Of course we can do that. It has a little additional cost and another six months, yes, we can do that thing and add that capability to it and you keep refining and perfecting and gilding the lily until it is no longer a lily. Proceed with something, stick with a plan, get it into operation, perfect it later.

Isn't that, Mr. Clinger, wouldn't you say that that is kind of our experience and a pattern?

Mr. CLINGER. Yes.

Mr. OBERSTAR. And I think that is advice well offered.

I am concerned also by your comment and the comments of previous witnesses that the approach to this system is too fragmented, that you have FAA, airlines, pilots, air traffic controllers. You have the international community, everybody is looking at this from a different perspective and at the outset when I was preparing with staff for this hearing, it certainly looked like here is something everybody is on board.

Everybody is singing from the same page on this issue and the more you dig into it, the more you find that there is this fragmentation, and we need to pull everybody together. Is that your sense, is that what you are saying?

Mr. MINECK. Yes basically. You know there are a lot of different factions. I think one of the factors is probably as an industry we haven't dealt with anything that is as broad in perspective as what we are talking about here.

It touches almost every piece of the aviation business, from the ground operating structures to the pilot operational procedures, to how the airlines actually operate within their own structures to—and the corporate and general aviation also from that standpoint, and as our aviation industry has evolved over the last not very many years, 50 years, all those pieces have come one at a time, and now we are looking at something that is suddenly going across all of them so all these individual organizations that have run their own piece of the business are being affected, and I guess I would promote within the U.S. we don't have a very clear place that that all really comes together.

We mentioned the FAA not having a plan. I honestly believe there probably is the basic structure of a fairly well thought-out plan but it comes forward in four or five different pieces. It comes forward as an operations piece, as a certification piece, as a standard. There is not really anything that pulls it all together so you can sit back as an industry and say, oh, now I see what is going on because we have a dialogue and a meeting and a set of discussions on one particular area. And then we will have another meeting and it will be like they are completely disconnected because they have a different set of timings and priorities and for this part of what is happening in the ground swell is coming from the industry, and I will give the industry a lot of credit because we are not willing to sit back and wait for all this. So there is a lot of individual things, with the airlines, we are going to prove that we can save money by doing this one little piece of the problem and I am going to go do that piece because I can save a lot of money for my airline. We heard that from Mr. Ferguson this morning and he is willing to do that and that is not really the right answer all along and I am not promoting that we wait, but we have to see how these pieces fit together or we will end up putting equipment and services in that in two or three years are going to change.

I would contend it won't take us very long to get that plan together because of the huge amount of work that has been done, but some kind of a forum is needed that will bring this together at a little higher level. Through your committee, through maybe the review you suggested our meeting, but we need a decision-making body that can take these issues and pick a path and say this is our national plan, this is where we are going and we are going to work with Europe and the other people that are influenced here.

Mr. OBERSTAR. Of all the technology that I have observed in the field of aviation in the years that I have been associated with it, nothing has excited the imagination as much as the GPS. It literally has the industry users, the airlines salivating to put it in practice and to realize the benefits from it.

I think clearly the air traffic controllers are excited about a new tool and a new dimension to their work. The manufacturers are excited about their potential at producing something that is really such a break through technology that gives us a leg up in the whole world.

FAA is excited about moving the United States a generation ahead of the rest of the world and yet there are these Gremlins in this system that threaten to stall it in ways that we have already heard about today.

It is too important a point in the evolution of aviation not to wrap it—wrap around it a clear and decisive program to move ahead at the quickest possible pace to bring everybody together on it in one forum.

Mr. Clinger, thank you for being so patient throughout this long day, I say to my colleague.

Mr. CLINGER. It is a fascinating hearing. It has really been one of the more interesting ones we have held for a long time. As you say, the potential for what we are talking about here is so enormous in terms of just so many areas that is going to mean so much to this country.

I think your point about we need to proceed full speed ahead, not wait for a total agreement or total coordination for this thing because I think ultimately we are so far ahead now that ultimately people are going to have to fall in line. That is going to be the result of this.

I just had one final question. To what extent could the potential benefits of GPS in your view be threatened if we are not able to meet the precision landing requirements of say of Category Two or Category Three. Do you think it is going to be possible to meet the standards for Category Two and Category Three and if not, what does that do? Does that diminish the potential for GPS significantly or not?

Mr. ESCHENBACH. I would be glad to answer that Mr. Clinger. Certainly we at Trimble have been building surveying systems that can address to the centimeter level already and it is only a matter of time before that capability is in the cockpit, so I am convinced that Category Two and Category Three will be achievable with GPS, there is not a doubt in my mind.

But to answer your question, if they weren't, is that a detriment to the system and does that in some way invalidate the system. The answer is absolutely not. Category One level approaches if we could just get them into the rest of the airports that are currently there that have no approaches or only noninstrument approaches that in itself would justify the entire system.

Mr. CLINGER. I think somebody testified to that, the vast number of these are Category One.

Mr. ESCHENBACH. Yes. Absolutely we have very few Category One, Two, or Three airports in the United States. Out of the 5,000 airports, only about 1,000 have approaches at all and it is well below 100 that have Category Two and Three approaches. To get Category One to the rest of the country would be a tremendous boon.

Mr. CLINGER. But your view we can achieve those.

Mr. ESCHENBACH. Absolutely, that will happen. I am convinced that will happen.

Mr. MINECK. I would share that same view. From a technical viewpoint, we have done enough testing to feel that GPS will achieve the accuracies that are needed, no automatic landing. We need to keep in perspective that we have been doing Category Three landings only 25 years ago in the world. And the ILS systems we had 25 years ago were not as good compared to today and they were probably not as good as we have available in GPS today.

My background happens to be all weather automatic landing systems as a technical specialty and from the dialogue we have had so far, I think if we look at the problem from the right aspect, it will be fairly straightforward to solve and we will get there, and I also concur with the observations that there is so much to be gained from GPS even if we don't do Category Two or Category Three that we should keep going.

Mr. CLINGER. Go forward.

Mr. MINECK. Absolutely.

Mr. CLINGER. On the jamming issue you indicated it is a failsafe system in terms of landings because it will give you a "we cannot compute" warning and therefore abort the landing.

What about just general navigation with the system? Is the possibility to jam it and have a Korean Air scenario that sort of gets you off course?

Mr. ESCHENBACH. You have got to distinguish between jamming and spoofing which are two distinct scenarios. The GPS is very difficult to spoof and it requires a lot of power, a lot of sophistication, and it is very tough to spoof it. Jamming is a little easier but in a jamming environment, it jams the failsafe so even in the en route environment it will jam in a safe manner.

Mr. CLINGER. So you would have redundancy.

Mr. ESCHENBACH. Yes, and in my years of flying GPS, I have never had a jamming incident that even occurred, much less caused a problem.

Mr. CLINGER. Right. Gentlemen, thank you very much.

Mr. OBERSTAR. I want to thank you for your contribution today and for your work in bringing us to this system, the companies that you represent, that is, and for your insights into GPS and its value to aviation.

And I certainly want to compliment the FAA on the tremendous work accomplished, being ahead of curve, as they have done. They certainly worked vigorously on an exciting technology and as in everything and in everything human, there are areas where more can be done and a better job can be done, and we have it within the capability and this is to me, Mr. Clinger, I would say a case where everybody wants the program to succeed and everybody wishes it well and wants to do the right thing. So I think that is a matter of getting everyone together and doing so.

And in the performance for today's hearing there was a splendid display, which can't be entered into the record because it is technology, pieces of equipment that glowed in the dark and in the light and demonstrate how this system works, and I want to thank Joe Orflin from the FAA and others of the FAA satellite office for the displays presented here in the committee hearing room that very tangibly demonstrated to the Members and to the visiting public the great contribution that GPS can make to aviation, is making to aviation, and of course what a great contribution it was to our hearings.

This is a matter which we shall continue to pursue in direct and indirect ways, and we have had a very enlightening insight today into the future of aviation.

The subcommittee stands adjourned.

[Whereupon, at 4:19 p.m., the subcommittee was adjourned.]

PREPARED STATEMENTS SUBMITTED

BY WITNESSES

Statement by John M. Beukers
Beukers Technologies
Before the Subcommittee on Aviation
House Committee on Public Works
and Transportation
Future Uses of Satellite Technology in Aviation
July 28, 1993

Mr. Chairman and members of the Subcommittee, my name is John Beukers. I appreciate being given the opportunity to appear before you today to present views of an independent consultant engaged in matters concerning the implementation and use of worldwide radio aids to navigation. This has been my professional discipline for close to 40 years and it has provided me with experiences relevant to introducing satellite technology into the inventory of aviation navigational tools. In recent years I have devoted much of my time in efforts to help realize the potential of satellite navigation. I hope my comments will be helpful to the Subcommittee deliberations.

Past experience has shown that to introduce a new navigation technology is a lengthy process spanning decades. Not only does the technology have to be evaluated for its suitability to meet requirements but the standards, procedures and certification for its use must be in place. Moreover, in the case of systems that involve the international community, a dialogue, negotiations, formulations and signing of constitutionally acceptable international agreements must be accomplished. It is only after this administrative effort has been completed that a stable market for equipment evolves, private sector investment commences and benefits accrue.

Satellite technology is following this path with one notable exception. Whereas in the past we have seen system use and markets for equipment evolve following the completion of administrative procedures, in the case of satellite positioning and navigation, the reverse is taking place. Aided by promotion, this space age technology has caught the imagination of the public, the airlines and other aviation users, government agencies, the international community – the list is endless. We are told that we must have this capability now and we find ourselves in a situation that can best be described as euphoric. In fact we have created somewhat of a dilemma with a technology being driven by market forces and user expectations rather than requirements.

This is particularly true with respect to aviation. The positioning, navigation, communications and control requirements for aviation are unique for safety reasons and require the formality of detailed operating procedures and specifications. Further, the international nature of air travel demands standardization to ensure that aircraft avionics and ground facilities have a commonality throughout the world.

There are many outstanding issues that must be resolved before we even contemplate certifying satellite positioning technology as the primary means of navigation for aviation use and decommissioning existing facilities. I have addressed these issues extensively and presented my findings at various professional society meetings over the last three years. Included with my testimony (**Attachment A**) is the last paper in this series presented to the Institute of Navigation at its annual meeting held in June of 1993 entitled *Administrative Procedures and Agreements Governing Global Radionavigation*. The material is included because it seems very relevant to this hearing.

It is fortunate that we in the United States have procedures and laws in place that must be followed to implement an international system of radionavigation and that we have the International Civil Aviation Organization (ICAO) to oversee the standardization process and the development of procedures. While these administrative hurdles are seen by some as hindering progress and preventing the immediate introduction and use of satellite positioning technology, they have been established to ensure a long-term safe and stable global airspace environment and, in my opinion, must be respected.

Until the United States and the international community agree upon an internationally operated and funded system, the only satellite positioning system that is close to operational status is the United States Global Positioning System (GPS) with the Commonwealth of Independent States (CIS) Global Navigation Satellite System

(GLONASS) in the wings with a questionable operational date. I will therefore focus my testimony on issues related to the United States' GPS.

Cost

At the top of the list of issues to be resolved is cost, cost sharing, and cost recovery. From the civil perspective GPS is a very expensive system. Its annual direct operating cost is $500 - $600 million according to a GAO study of Defense Satellite Programs and Launch Activities done in June of 1990 (GAO/NSLAD-90-154FS June 90). The findings are detailed on page 6 of **Attachment A**. This figure does not include indirect costs, the cost of augmentation satellites and/or terrestrial augmentation and communications necessary for GPS to meet the stringent requirements of aviation.

GPS direct and indirect costs can be categorized as:

- Replenishment space vehicles
- Replenishment launch vehicles
- Launch and range support
- Operational control and maintenance
- Supporting software maintenance
- Support infrastructure depreciation
- System administration
- Augmentation satellites
- Land-based augmentation
- Local monitoring
- Communications
- User information network

The cost is considerably higher than it need be due to the military mission, defense procurement activities and hardware carried on the satellites that is irrelevant to positioning.

The realization of any significant cost savings by phasing out existing systems is perhaps 10 years away and some even challenge the wisdom of a non-redundant, single satellite system for aviation navigation.

The United States has made commitments to the world that it will unilaterally finance GPS for 10 or 15 years and more recently has made this open-ended by making the time limit "the foreseeable future". It follows that no cost recovery is contemplated from the international community.

One must conclude that civil satellite navigation will either continue to be subsidized by the United States Government, the Department of Defense (DOD), the Department of Transportation (DOT) or an additional burden of cost will have to be borne by the civil community and users.

Key questions are: who pays, who benefits, and, in the long term, who shares the cost when the Department of Defense turns to an alternate system for its positioning and navigation requirements? In my view we should be looking at an internationally operated and funded system that takes the burden of total cost off the United States taxpayer.

Dichotomy of Purpose

Perhaps the most difficult issue to resolve is the dichotomy of purpose between the Department of Defense's requirements for national security, protecting United States international interests, and, on the other hand, meeting the stringent safety requirements of civil aviation. The Department of Defense has clearly stated its intent to retain the restriction on the high accuracy transmission of GPS on the grounds that a potential aggressor to United States interests could use the transmission for weapon targeting and delivery and deny the United States its advantage. For civil use the transmissions are deliberately scrambled to introduce errors of position. However, the high accuracy signal is legitimately required by users throughout the world and, in particular, by the aviation community in any terminal area navigation. The result has been a proliferation of localized receiving and communication systems that transmit corrections, thereby negating the Defense Department's objective. To improve GPS performance over a wide area, as opposed to local corrections, aviation interests are proposing and adopting additional satellite transmissions to overcome the effects of the deliberate performance degradation.

Various Defense Department interests are genuinely concerned about the global proliferation of these systems, in particular, any wide area attempts at restoring the inherent GPS accuracy. As a result, the DOD may find it necessary to take action to re-establish its initiative. However, without the high accuracy signals, GPS will be of little value in the terminal area for aviation navigation.

System misuse has to be addressed at the international level through the United Nations so that such action can be condemned in the Security Council and appropriate remedies imposed, however, *the potential of system misuse should not become the reason for denial of an important and beneficial technology.* International cooperation will be required.

Technical Issues

GPS was not intended to meet the full requirements of civil aviation but it is now being applied to do so. This gives rise to a number of technical issues that are receiving intensive study both in the United States and overseas.

There is a need for a *civil signal specification* which must include a definition of the number of satellites that constitute an operational constellation together with the probability of signal availability. Further, the *source of system status information* for civil operation must become the responsibility of the agency controlling the system operation.

The GPS constellation of 21-24 satellites requires various forms of augmentation from the ground or additional satellites to meet the high integrity, reliability and availability requirements of aviation. Of particular importance is the *signal integrity* in the terminal area during the final phases of flight. At this time the number of satellites in view and operational, masking by hills and local structures and interference, both intentional and unintentional, are critical. It has to be recognized that the GPS or any satellite navigation signal is extremely weak and in this respect is vulnerable to interference.

The issues of intentional *jamming* of GPS being employed for the landing phase of flight has been raised but is generally dismissed on the grounds that there is no historical precedence for this. In my opinion this possibility should be given more careful consideration. It is very difficult to jam an Instrument Landing System, the signal levels are high and increase in an aircraft's receiver upon approach to the runway. In comparison, the low level GPS satellite signal does not change in amplitude during approach. It is relatively easy to jam a weak navigation satellite signal from several miles off with a small transmitter as has been demonstrated by an investigation made by the Defense Research Agency (U.K.) under a project for the Civil Aviation Authority (CAA U.K.) (*A Review of the Interference and Jamming Resistance of SPS SPG Receivers for Aviation*, May 1992.)

Resolution of these technical system design issues and an assessment of the threat of deliberate interference have to be made to the satisfaction of those responsible for the safety of air travel.

International Agreements

Bringing satellite positioning technology into the United States national airspace is complicated by the satellite system's global coverage. The United States can make a unilateral decision to employ GPS in its national airspace but the full benefit to aviation will only be derived through international acceptance. The airline industry would be penalized if its aircraft were obliged to carry a multiplicity of avionic equipment to interface with different ground facilities at airports around the world.

Unlike systems such as the Very high frequency OmniRange (VOR), Instrument Landing System (ILS), or Microwave Landing System (MLS), orbiting satellite navigation transmissions extend beyond territorial boundaries and national airspace. The transmissions can be employed by operators remote from and not necessarily associated with the service provider. The service provider has no indication of who is using the system and has no control over the system's use other than to scramble the transmissions or remove them from service. We must accept, therefore, that we are dealing with the global airspace and international use and be prepared to address the implications.

It is generally recognized that for safety and a smooth transition between airspaces, radio aids to navigation employed by any form of transportation traveling from one nation to another require a guarantee of availability, performance and commonality of specification. This calls for international cooperation to reach a consensus and to enter into appropriate agreements. For aviation over the past 50 years this procedure has been relatively straightforward and has been performed by the ICAO. In the case of VOR, ILS, and MLS, once the performance had been proven to meet an established set of operational requirements, it was a relatively simple matter for the ICAO Air Navigation Council to act on the recommendation to adopt the systems and mandate their use. Each member nation is then responsible for installation, operation, and maintenance and all the associated costs. It is left to the individual nation to define a cost recovery policy and enact legislation for the collection of fees and charges if this is deemed necessary.

The advent of global navigation has added a new dimension as has been demonstrated by the Omega and Loran-C terrestrial radionavigation systems. The international agreements between the United States and other countries to implement and operate these systems provides precedence for international agreements covering satellite navigation. There are constitutionally acceptable procedures for entering into international radionavigation agreements that have been followed by those associated with the implementation of Omega and Loran-C. A detailed discussion of the procedures pertinent to these systems is contained in **Attachment A** on pages 4 and 5. It is my experience that few in the technical community, both within the government and in the private sector, are aware of and understand the legal requirements for these procedures. The situation can be rectified by better training and educating the involved government officials and others interested in the process. This will help ensure that the administrative effort receives an appropriate amount of attention.

Ownership and Control

On the premise that the United States endorses global use of satellite positioning technology for aviation and we are not only concerned with U.S. airspace, it is imperative to include the international community in current activities and long-range planning. To some extent this is taking place through ICAO in the All Weather Operations Panel (AWOP) and the Future Air Navigation System Committee (FANS). The issue of the system control and ownership and the concomitant issues of liability and insurance are at the top of the international community's agenda. Even if we are successful in the United States in landing aircraft on an operational basis using augmented GPS, the probability of landing a 400 passenger aircraft at international airports around the world using a United States DOD operated system is virtually zero. Many of these airports require guidance to touchdown and the navigational aids to perform this operation are covered by national law; ownership is a prerequisite.

It is not realistic to expect the international community to be in any position to accept the United States GPS now or in the future as an international standard system, particularly for terminal navigation, under the current arrangement of verbal representations of ownership and control and promises and commitments of continued GPS funding.

Statements made by United States government representatives are treated with some skepticism and, unless followed up by formal agreement, it seems more than likely they will be disregarded. There are grounds for this attitude. The United States led the initiative for getting the world to adopt the Time Reference Scanning Beam MLS through ICAO in 1978. The All Weather Operations Panel of ICAO has substantially completed its work on the specification and procedures for implementing MLS and the loose ends are to be submitted at the Whole World ICAO meeting in 1995. Even before the MLS system implementation program has started there are voices in the United States calling for its rejection in favor of developing a landing system based upon GPS. Meanwhile other nations are moving ahead with MLS implementation.

Three years ago the Federal Aviation Administration (FAA) was fully supportive of the United States Loran-C program but now, with 120,000 - 130,000 General Aviation aircraft flying Loran-C, the FAA appears to have all but abandoned the system in favor of GPS, leaving a decimated industry and a bewildered public. Over five years ago the National Association of State Aviation Officials (NASAO), at the FAA's request, submitted a list of 500 preferred non-precision airport approaches for Loran-C certification. Because the FAA's resources are being almost totally devoted to GPS development this work has not been completed. In fact, the 125 Loran-C approaches that Congress has directed the FAA to promulgate appear nowhere near completion despite this heightened Congressional attention.

What happens after the euphoria surrounding GPS subsides and DOD announces, as it has done with Omega and Loran-C, that it no longer has a need for the system and the costs ultimately have to be borne by the civil aviation community?

The history of prematurely jumping from one technology to another makes for confusion, disrupts markets and leads to unnecessary taxpayer and user costs. This is not lost on the national and international community. Ownership and control are of serious concern to the entire aviation (and other) communities and it is an issue that must be given thoughtful consideration in view of the long-term ramifications.

Conclusion

Positioning and navigation by satellite have considerable potential which, in my opinion, will only be realized fully when it is adopted formally in concert with satellite communications. New specifications, operational requirements and procedures will have to be formulated within the Panels and Committees of ICAO and recommended for adoption by the ICAO Air Navigation Council and an international agreement with a satellite service provider will be necessary.

It will probably take up to 10 years to conduct the administrative support work for a worldwide satellite navigation system. GPS should be used as a test bed during this period to determine the capabilities and limitations of satellite navigation technology and demonstrate the effectivity of procedures. During this period the United States should cooperate with the international community to implement a World Satellite System that would be funded, operated and policed internationally. Such a system will cost substantially less than GPS and will result in internationally shared costs leading to considerable savings for the United States taxpayer and aviation users.

That completes my testimony. Thank you for giving me the opportunity to participate in this important hearing. I will be pleased to respond to any questions you have for me.

Attachment A

Administrative Procedures and Agreements Governing Global Radionavigation

Presented at the
49th Annual Meeting of the
Institute of Navigation

Cambridge, Massachusetts
June 21, 1993

by
John M. Beukers

Beukers Technologies
Vero Beach, FL, U.S.A - Longborough, Glos., U.K.

Administrative Procedures and Agreements Governing Global Radionavigation

John M. Beukers
Beukers Technologies
Vero Beach, Florida

BIOGRAPHY

Three years after graduating from London University in 1954, Mr. Beukers emigrated to the United States to continue a career in radionavigation working on the development of doppler radiodirection finders and the doppler VOR. In 1963 he formed Beukers Laboratories, Inc. specializing in the implementation and use of Loran-C, Omega and VLF Communications where he pioneered navaid retransmission technology now used worldwide to track balloon-borne meteorological weather probes.

Twice winner of the ION's Burka Award for the best paper of the year, he has authored numerous papers covering the radionavigation discipline. He is a Fellow of the Royal Institute of Navigation, a member of the IEEE, the ION and a Director of the International Navigation Association, and the Wild Goose Association.

Mr. Beukers is currently a consultant and writer on radionavigation matters devoting much of his time to finding a rational approach to realizing the potential of global satellite navigation technology.

ABSTRACT

Worldwide radionavigation systems in use today have evolved over the past 50 years to meet common national and international requirements for transportation. This has been possible through the coordinated efforts of member states to international organizations. Today, the apparent urgency to apply advancements in radiolocation and communication technology is challenging the conventional, slow but methodical, international administrative machinery. In an attempt to speed up the regulatory process, some nations and organizations - driven by impatient special interests - are developing unilateral initiatives. This paper discusses the mandatory procedures that must be followed under United States law to become a signatory to an international agreement and reviews the current international agreements covering worldwide radionavigation systems.

INTRODUCTION

During the past few years, the potential of radio positioning and navigation using satellite technology has been demonstrated many times over to the point where some would consider it has been oversold. There is no question as to the utility of satellite technology to a wide range of applications. Technology enthusiasts, industry's marketeers, users, and even some operations personnel are champing at the bit waiting for the day when satellite navigation becomes a certified operational reality. But in our enthusiasm are we not overlooking the real but dull world of legislation and administrative procedures?

From the time that the Constitution of the United States was written our legislators have wrestled with and passed laws designed to provide an orderly society with safeguards against the abuse of our freedom. Cumbersome and irritating that these laws may sometimes seem, even misdirected at times, we have to accept that over the years the legislative branch of government has done a remarkable job in fashioning the progressive society that we in the United States currently enjoy.

Technological developments today are taking place at a breathtaking pace and many of these have the potential of improving our quality of life. But bringing these on line is not at all easy since they must interface with established laws that have evolved over the years and will not be changed overnight for our convenience. *We cannot just ignore the existence of regulatory procedures for the sake of expediency, for to do so would be counterproductive to reaching the end objective.*

This paper presents some of the pertinent United States legislative and administrative requirements that are a prerequisite to establishing satellite technology in an international environment. It is the author's assessment that the existence of much of the material presented here is not widely known, and, if it is, the requirements are poorly understood. This is confirmed by internal agency memoranda directing personnel involved in international radionavigation affairs to become familiar with the mandatory administrative procedures.

Of topical importance are the current controversies over the United States Global Positioning System (GPS) and the international community's desire to have control, ownership and funding of satellite radionavigation technology under the umbrella of an international consortium or organization. Such a system has been given the name of the *Global Navigation Satellite System*, or GNSS.

WHY DO WE NEED AGREEMENTS?

There are some who take the position that with a full constellation of 24 space vehicles, the United States Global Positioning System is here, it's free, it will satisfy the requirements of a GNSS, and the world will simply latch onto and use the system. To this mind set the need to start down the path for an international GNSS and to an international agreement is redundant, onerous, unappetizing, and even unnecessary. With all due respect to those who subscribe to this point of view, the author suggests that it is naive and without precedence. In the longer term, if this thinking is allowed to take root, the formal use of satellite technology for global navigation could well be set back 10 or 20 years and may never achieve its potential. Time is not on our side; addressing and resolving this issue must receive the highest priority.

In order to be internationally acceptable, it is generally recognized that for safety and seamless navigation, radio aids to navigation employed by any form of transportation travelling from one state to another require a guarantee of availability, performance and commonality of specification. This calls for international cooperation to reach a consensus and to create appropriate agreements. For the past 50 years this procedure has been relatively straightforward being undertaken by international bodies such as the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), and the International Association of Lighthouse Authorities (IALA). The advent of long-range and global radionavigation systems has introduced a new dimension of complexity to formulating workable agreements. Transmissions of these systems extend beyond territorial waters and airspace and are used by those remote from, and not necessarily associated with, the provider of the service. This gives rise to issues of cost, cost recovery and acceptable cost sharing; guaranteed performance and availability - both short (10 years) and long term (50 years or more); and the legal concerns of insurers and others relating to exposure, liability, and responsibility.

THE PAST HAS BEEN SIMPLE.

It is important to differentiate between short-range, local systems common to worldwide use and long-range systems used globally. In the case of local national systems, like the Instrument Landing System (ILS) and the VHF OmniRange system (VOR), for example, once the performance had been proven to meet an established set of operational requirements, it was a relatively simple matter for the ICAO Council to act on recommendations to adopt the systems and mandate their use. Each member state was then responsible for installation, operation and maintenance and all the associated costs. It was left to the individual state to define a cost recovery policy and enact legislation for the collection of dues if this were deemed necessary.

With the advent of the global VLF Omega system and more recently the worldwide long-range Loran-C system, cooperation between states providing the service has become necessary to ensure contiguous signal coverage, continuity of service and to receive international acceptance. Operational and logistical support agreements covering these systems include sections relating to cost, cost sharing and division of responsibilities. This finds us in the world of International Agreements.

WHAT CONSTITUTES AN INTERNATIONAL AGREEMENT?

Reporting under the Case-Zablocki Act, Public Law 92-403

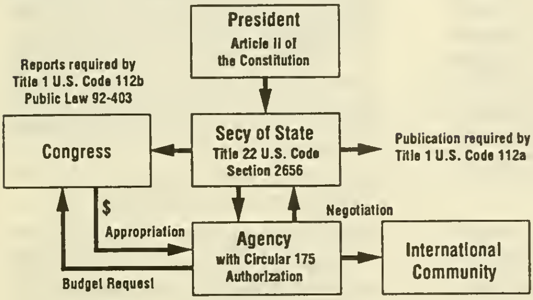
For a definition of what constitutes an international agreement we turn to Title 22 of the Code of Federal Regulations (CFR), Department of State, Subchapter S. Under part 181 - Coordination and reporting of international agreements, paragraph 2: *Significance of the arrangement* provides examples of arrangements that may constitute an international agreement. Example iv states: agreements that "involve continuous and/or substantial cooperation in the conduct of a particular program or activity such as scientific, technical, or other cooperation, including the exchange or receipt of information and its treatment, or the pooling of data ....." may qualify.

Further, under paragraph 5(e), *Oral arrangements* "Any oral arrangement that meets the criteria discussed in (previous paragraphs) is an international agreement and must be reduced to writing by the agency that concluded the oral arrangement and is subject to all the requirements of the Act...."

Considering the current and past actions of the United States government in respect of giving GPS to the world free of charge and offering to share data through a federally funded office (GPS Information Center) and the future promises of a 10 year or more commitment would suggest that the United States government has already unilaterally entered, perhaps unwittingly, into an international agreement that remains undocumented. But in any event, it is difficult to see how the government can legally avoid entering into a multilateral international agreement if GPS is to be formally endorsed worldwide.

HOW DOES THE UNITED STATES BECOME A PARTY TO AN INTERNATIONAL AGREEMENT?

There is a formal legislative process that enables the United States to become a signatory to an international agreement. The procedures have been used in every international radionavigation agreement to date and apply to all agencies, the Department of Defense included. The process is depicted in the diagram.


President
Article II of the Constitution
Reports required by Title 1 U.S. Code 112b Public Law 92-403
Congress
Secy of State
Title 22 U.S. Code Section 2656
Publication required by Title 1 U.S. Code 112a
$
Appropriation
Negotiation
Agency
with Circular 175 Authorization
International Community
Budget Request

> The President, under Article II of the Constitution, is empowered to enter international agreements. This authority can be transferred to an agency of the government through constitutionally authorized procedures.

Powers of the President

Under Article Two, Section Two, of the Constitution of the United States, the Powers of the President are stated. Paragraph 2 gives the President the power to make treaties. It is, however, the delegation of this authority to the Secretary of State that is more meaningful in day-to-day business and pertinent to entering into international agreements. Under Title 22 of the U.S. Code, section 2656, entitled *Management of foreign affairs*, the Secretary of State is given sweeping authority to conduct matters in foreign affairs "intrusted to him by the President" and "in such a manner as the President directs."

Foreign Relations

Of more substance to the evolving GPS/GNSS technology are the subsequent sub-sections 2656 a, b, c, and d that address scientific and technological advances and their impact on foreign policy. The responsibilities of the President and the Secretary of State in this regard are clearly stated. While space does not permit a full extract of the text, a selection of quotations may be helpful in putting the Administration's involvement and responsibility with GPS and GNSS into perspective.

Section 2656a *Congressional declaration of findings of major significance of modern scientific and technological advances on foreign policy.* Congress finds that "....appropriate knowledge of modern science and technology by officers and employees of the United States Government are essential in the conduct of modern diplomacy"; "....the United States Government should seek out and consult with both public and private industrial, academic, and research institutions concerned with modern technology"; "the effective use of science and technology in international relations for the mutual benefit of all countries requires the development and use of the skills and methods of long-range planning".

Section 2656b *Congressional declaration of policy regarding consequences of science and technology on conduct of foreign policy.* ....the Congress declares the following to be the policy of the United States: "Technical opportunities, impacts, changes, and threats should be anticipated and assessed"; "The mutually beneficial applications of technology in bilateral and multilateral agreements and activities involving the United States and foreign countries or international organizations should be recognized and supported as an important element of United States foreign policy"; "The United States government should insure that....employees **of the United States Government engaged in formal and informal exchanges of scientific and technical information, personnel, and hardware are knowledgeable in international affairs.**" (Author's emphasis added.)

Under the responsibilities of the President, Section 2656c cites that the President in consultation with the Director of the Office of Science and Technology Policy shall identify and evaluate elements of major domestic science and technology programs and activities of the United States government with significant international implications. Additionally the President is required to report to Congress and the Senate, not later than January 31st each year, on all aspects of bilateral and multilateral activities involving science and technology and the implications on foreign policy.

Finally Section 2656d covers the responsibilities of the Secretary of State. It is here that the Secretary is given the "primary responsibility for coordination and oversight with respect to all major science or science and technology agreements and activities between the United States and foreign countries, international organizations etc......"

In the execution of these responsibilities the Secretary is required "to enter into long-term contracts, including contracts for the services of consultants, and shall make grants and take other appropriate measures in order to obtain studies, analyses, and recommendations from knowledgeable persons and organizations with respect to the application of science or technology to problems of foreign policy".

It should be clear from the foregoing, with perhaps a reading of the complete text, that, in their wisdom, past legislators have put the responsibility of interfacing United States science and technology with the world on the shoulders of the President and the Secretary of State. How then does an agency of the government become legitimately involved in international affairs that embrace GPS or GNSS?

The Circular 175 Procedure

By means of a document known as *Circular 175 Authorization*, the Secretary of State, through the legal staff at the Department of State, can issue a specific and limited authorization delegating authority to a named agency to interface and conduct negotiations with the international community. In doing so the Title Code of the agency is cited to ensure that the Circular 175 Authorization is consistent with the charter of the agency.

The origin of Circular 175 Authorization is a Department of State circular #175 dated December 13, 1955, a codification of which is to be found in the Foreign Affairs Manual, Volume II, section 700. This is a short section, well worth reading for those involved in international affairs. Authorization under Circular 175 carries with it additional responsibilities for reporting back to the Secretary of State the result of activities conducted under the authorization. The reporting time is 20 days to enable the Secretary of State to meet the letter of Public Law 92-403 commonly referred to as the Case-Zablocki Act or simply the Case Act.

All is not finished at this point. If any expenditures are required to meet the commitments negotiated under the Circular 175 Authorization, these must be budgeted funds appropriated in the normal budget cycle process. Once funded the agency is then able to fulfill its negotiated obligation with the foreign counterpart(s).

IS GPS OR A GPS-BASED GNSS EXEMPT FROM THIS PROCEDURE?

It is difficult to see how a major technological advance that has cost the United States upwards of $10 billion and probably close to $20 billion can escape the definitions contained in the referenced documents. In fact it would appear that the conduct of some United States Government employees in their enthusiasm may have unknowingly crossed the fine line between general technical discussions and committing the United States government to future activities and expenditure. It is the author's understanding that the purpose of the Case Act is to ensure that public officials act only in accordance with State Department authorization and that there is an audit trail to show this to be so. To the author's knowledge no Circular 175 has been raised for GPS activities or negotiations. In addition there appears to be no controlling documentation from the Department of State to provide guidance to federal employees on GPS/GNSS issues in the international forum as required by law. Such guidance might prevent conflicting statements being made by different agencies of the U.S. government that are not necessarily consistent with the policies stated in the current 1992 edition of the Federal Radionavigation Plan.

HOW HAS THE PROCESS WORKED IN THE PAST? PRECEDENCE WITH OMEGA.

Omega followed a long, tortuous route from a United States Navy DOD system to a civil international system. So here is an example relevant to satellite navigation and offering precedence. Examination of the paper work shows that the United States entered into a number of international agreements over a twelve-year period between 1968 and 1981.

1. Bilateral agreements with Argentina, Australia, France, Liberia, Norway, and Japan, negotiated by the Department of State with U.S. Navy participation; 1970-1978.
2. Umbrella Agreement: Principles of the Coordination of Operation of the OMEGA Radionavigation System by an International Omega Technical Commission. Effective date December 21, 1981; renewed June 6, 1991.
3. Individual bilateral OMEGA station agreements with Argentina, Australia, France, Liberia, Norway and Japan; negotiated by the U.S. Coast Guard, 1977 and continuing.
4. Support Agreements with the same countries.
5. Monitoring Station agreements with a number of countries.

All of these agreements were negotiated under individual Circular 175 authorizations. The first of these was granted to the U.S. Navy in 1968 with subsequent new grants to the U.S. Coast Guard. Today, appropriations for funding are made through the Coast Guard budget process in accordance with the requirements authorized by the currently active Circular 175.

As a matter of interest, OMEGA system management and total financial responsibility was formally transferred from the Navy to the Coast Guard on October 1, 1980. The total annual system cost to the United States today is $5-8 million.

What can be learned from the Omega experience? First, all negotiations were made in strict accordance with the Circular 175 authorizations. Internal memoranda show that there has been a continuous and professional effort by the Coast Guard to confer with its legal department to ensure that it was in compliance with the delegated authority and reporting requirements. Second, that it took 12 years to achieve an international agreement, 7 years of which were consumed in bringing the system into the civil arena. Third, that Circular 175 authorization is not necessarily transferable from one agency to another if the title in the U.S. Code under which the authorization was granted changes in the process.

PRECEDENCE OF LORAN-C

In the case of Loran-C there are international agreements involving the United States and those strictly between nations, independent of the U.S. - the latter stimulated by the withdrawal of the U.S. from Loran-C operations overseas.

1. DOD agreements for the original overseas Loran-C installations.
2. Bilateral agreements between the U.S. and Canada (5), over the period 1964-1991.
3. Agreement between the U.S. and the U.S.S.R. for establishing joint Loran-C/Chayka Radionavigation Systems; May 31, 1988.
4. International Agreement Concerning the Establishment and Operation of the Civil Loran-C Navigation System in North West Europe and the North Atlantic; August 6, 1992.
5. Agreement on an International Programme for the Joint Radionavigation Service in Far Eastern Waters Using Loran-C and Chayka Stations; September 8, 1992.
6. Development of Loran-C in the Mediterranean Area; February 11, 1993.

What can be learned from these established agreements? First, as with OMEGA, negotiation of all international agreements involving the U.S. was conducted under a series of Circular 175 authorizations with the exception of the one with the U.S.S.R. which was signed by the then Secretary of State George Shultz[1]. To transfer Loran-C assets overseas to host countries will almost certainly be covered by a new Circular 175 Authorization currently being requested. Second, and of relevance to a GNSS agreement, if appropriations for funds are required to be addressed in the negotiations leading to the signing of an agreement, another dimension is added to the process that can frustrate progress towards the eventual signing. Funding appropriations usually necessitate passage of a bill in Congress or Parliament(s) where party politics and special interests play a major role. Technological advance and operational requirements are more than likely to take a back seat. It is no secret that this was the experience of the Europeans in their deliberations leading to last year's signing of the North West Europe Loran-C agreement in which the amount of money involved was comparatively insignificant.

THE GPS/GNSS INTERNATIONAL AGREEMENT

With this rather bleak perspective, what is the motivation for generating an international agreement for funding and operating a GNSS when we have been forewarned of an extended period of negotiation and the frustrations of reaching a politically acceptable consensus?

The motivation must surely be to have in place an agreement, legally binding under international law upon which to build a GNSS. Without such an agreement all the talk in the world will not lay a sound and reliable foundation. The issues are well known; here is a sample:

Ownership:	Participation, Control, Operation
Financial:	Funding, Costs, Cost Sharing, Revenue Generation
Political:	Availability, Misuse, Conflicts, National Security
Legal:	Liability, Insurance, Frequency Allocation
Technical:	Specifications and Performance

With the exception of cost, these issues will probably be resolved by some soul-searching give-and-take. The extraordinary high cost of satellite technology presents a serious threat to realizing a system unless the total annual costs can be established and a determination is made as to who is going to pay for the service. Should not answers to these questions be found *before* a navigation infrastructure dependent upon satellites is created? To the author's knowledge no serious attempts have been made to find an adequate source of revenue and the reason is simple - the United States has thoughtfully put off the day of reckoning for a decade or more!

The closest contender for a GNSS at the moment is GPS, and if this system were to become the basis for a GNSS and an international agreement, we need to look carefully at GPS costs and determine if this expenditure can be borne by the international civil community. GPS direct and indirect operational costs can be categorized as:

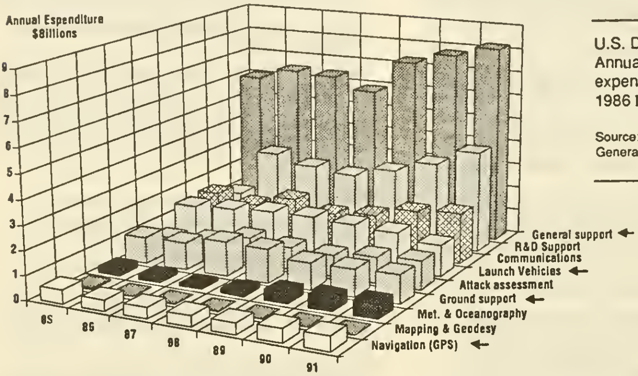
1. Replenishment space vehicles
2. Replenishment launch vehicles
3. Launch and range support
4. Operational control and maintenance
5. Supporting software maintenance
6. Support infrastructure depreciation
7. System administration
8. Augmentation satellites

---

[1] To be strictly accurate, a small number of Loran-C agreements slipped by the Circular 175 authorization procedure due to an administrative oversight but were subsequently ratified.

9. Land-based augmentation
10. Local monitoring
11. Communications
12. User information network

An analysis of some of these costs is found in the General Accounting Office Report of a study of the U.S. Air Force space program conducted for the Chairman of the Committee on Armed Services, House of Representatives in 1990.



U.S. Dept of Defense Annual Space Program expenditures from 1986 to 1991.

Source:
General Accounting Office

A graphic representation of GAO data shows 7 years of expenditure over the period of 1984 to 1991 on the space program conducted by the Department of Defense. It is to be noted that there is a direct line item for GPS running at an annual rate of $500-$600M, R&D being broken out as a separate line item. Of more significance are the line items of ground support; launch vehicles; and the large $8 billion expense of general support. How are these indirect expenditures to be treated? Should a proportion be allocated to navigation, and, if so, what percentage? Or should these support functions be treated as being required for other programs and therefore not burden the navigation service? Answers to these questions are required to determine the true cost of GPS to be put on the table in negotiations establishing GPS as a candidate for the basis of a GNSS covered by international agreement. But what are the chances of the costs being accepted?

DISCUSSION

In today's climate of global budget constraints and tight money, GPS costs are likely to remain a roadblock to GPS acceptance as an international system. Here is the rationale. If a cost sharing approach can be reached for the direct annual GPS operational costs and none of the support costs are included, then it will be recognized that the navigation service is receiving a substantial subsidy from the Department of Defense appropriation and is therefore subject to Congressional budget review. To acknowledge and provide for this on-going subsidy in an international agreement will be difficult, if not impossible, to negotiate. On the other hand if the real operational cost is developed by allocating a proportionate amount of the support costs, the $1 to $2 billion annual cost would be prohibitive and unacceptable to the international community.

If neither of these options is acceptable, where do we go from here? There appear to be just two directions; either we let GPS just "happen" to be employed at the users' risk without international agreement, and with the U.S. footing the total bill for an indeterminate future, or we start down the road to a cheaper, perhaps backwards compatible, internationally funded and operated system covered by international agreement.

Unfortunately inter-agency squabbling; differences of opinion within the technical and operational communities; and the stated opposition by DOD staff to creating an independent international system; confuse the picture and make it difficult to address the alternatives in a rational manner. The DOD's claim that the standard positioning service (SPS) of GPS is under civil control and therefore GPS is a civil system meeting the requirements of global radionavigation is, to put it politely, a weak argument greeted with suspicion and uncertainty. It is analogous to saying that passengers on a bus control its destination. Make no mistake - if we elect to board this bus as a passenger, we have no choice but to go where the driver takes us.

It must be made crystal clear that contrary to what is desired by the U.S. political leadership, the U.S. DOD's current position and agenda is to maintain the satellite navigation initiative by retaining the selective availability degradation; discouraging or even withholding endorsement for wide area differential schemes; preventing the emergence of an alternative independent capability; and retaining ultimate control of GPS by the refusal to accept any monetary support from sources other than its own appropriations. This is a justifiable position on the grounds of national security but to represent that any aspect of the system is under civil control is not credible.

The depth and intensity of the current debate on these contradictions can be judged by President Clinton's stated support of transferring GPS to civil control as a means of realizing the benefits of defense expenditures, echoed by the Secretary of DOT Federico Pena; the formation of a *closed* DOD-DOT inter-agency task force at Secretary level to resolve these differences and establish a common policy; and the remarks made by Senator Exon on April 30, 1993 from the Senate floor regarding turning GPS over to the DOT and the need to start a dialogue on user fees.

In the international arena the contradictions are just as intense. The U.S. representatives to the ICAO FANS Committee Meeting of the Whole held in London during May 1993 had the difficult job of convincing the committee that SPS signal of GPS is under civil control and therefore any military connotation could now be avoided. Following the meeting it was reported in the United States that all objections to the use of GPS as the civil GNSS system had thus been overcome. A reading of the meeting minutes reveals otherwise suggesting that the arguments were not convincing. DOD cannot have it both ways without raising questions as to the agency's integrity. How in the world can a Circular 175 Authority be generated to conduct negotiations for an international agreement for a GNSS involving GPS in this climate?

Removing Obstacles

To get the show on the road, the first priority must be for DOT and DOD to get their act together with a policy that can be supported by Congress, the Senate and the Cabinet. It is ironic that the vehicle for doing this is the Federal Radionavigation Plan which, it is admitted, has been tossed to the wind in the current furor. Next the United States needs to develop a short term (10 year) and long term (50 year) strategy involving the international community in which GPS will play a major but not the only role. Finally under the established legislative procedure, the U.S. must start down the long and tedious road to become a signatory to an international agreement covering satellite navigation. It is the author's estimation that this will take 10 years or more to negotiate and will rank along with the GATT, NAFTA and Maastricht negotiations but will be in force when a GNSS finally materializes.

And if one were to be so bold as to offer a word of caution, if the United States and the international navigation community cannot come to an agreement for the funding and operation of a GNSS and GPS becomes the only available system by default, navigation by satellite could remain a supplemental navigation tool indefinitely.

CONCLUSION

In his statement from the Senate floor concerning the future of GPS, the United States Senator from Nebraska, Jim Exon, Chairman of the Armed Services Committee subcommittee and a senior member of the Commerce Committee, has provided the basis for the conclusion to this paper. In his dissertation the Senator suggests that GPS will benefit the world economy; revolutionize the movement of people, goods, and services the world over; bring enormous productivity improvements to the world's shipping and transportation industries; provide every nation in the world with substantial economic benefits; profit U.S. industry and impact U.S. balance of trade. At the same time the Senator recognizes that it is U.S. policy for GPS to be a technological give-away at the U.S. taxpayers' expense for the foreseeable future with a further commitment to provide six years notice of any intent to change this policy.

Since the Senator's statement requests the cooperation of the President and relevant cabinet officials to chart a course for GPS management, his statement requires our serious attention. While being no lawyer, a layman's comparison of the language used in the Senator's statement with that of the discourse on the implementation of the Case Act for the reporting of international agreements and the Circulation 175 procedures, suggests that GPS should already be the subject of an international agreement - ***except for one important difference.***

The criteria established in subchapter S section 181.2 of Title 22 of the Code of Federal Regulations states "**The parties to an international agreement must intend their undertaking to be legally binding .... and intend their undertakings be governed by international law**".

This is the root of the problem that is preventing GPS from becoming internationally acceptable as the basis for a GNSS. There appears to be no intention for the United States to become legally bound to its stated policy. The cavalier attitude of some in government service towards binding agreements and those responsible for the implementation of radionavigation policy as documented in the 1992 edition of the Federal Radionavigation Plan is confirmation enough for the international community to be extremely cautious in accepting statements of U.S. policy on blind faith without a legal footing. This is echoed over and over again by those throughout the world wrestling with the adoption of satellite technology.

We must come to the inevitable conclusion that for GPS to qualify as a candidate for an international system it must be covered by a constitutionally acceptable international agreement. As soon as this is recognized and negotiations commence, discussions on institutional issues will find an avenue for resolution.

RECOMMENDATION

Without delay, the GPS issue should be taken up with the Secretary of State to provide guidance in accordance with the Secretary's responsibilities as defined in Title 22 Section 2656d which is relevant in its entirety.

ACKNOWLEDGMENTS

To personnel at the Volpe National Transportation Systems Center for their encouragement to the author to research the legal and administrative aspects of International Radionavigation.

For the invaluable assistance provided by current and retired U.S. Coast Guard personnel who researched the archives of 20 years or more to provide the historic references upon which this paper is based.

To the many professional colleagues who have devoted many hours of fax and phone time providing information and sharing thoughts on the subject.

REFERENCES

Information contained in the following references was used as background material in the preparation of this paper.

Legal and Administrative

1. Publication of Treaties and Other International Agreements of the United States: Act of September 1950 Title 1 United States Code 112a. Requires the Secretary of State to have compiled an annual list.
2. Transmission of International Agreements other than Treaties to Congress: Public Law 92-403, 92nd Congress, S.596, August 22, 1972. Known as the Case-Zablocki Act. Amendment to Title 1, United States Code inserting section 112b between sections 112a and 113. Requires 60 day notification to Congress.
3. U.S. Code Annotated Title 22 Foreign Relations and Intercourse. Title 22 Code of Federal Regulations, Change 1 (4-1-87 Edition) pages 471-477. Subchapter S, International Agreements, Part 181. Coordination and reporting of international agreements.
4. The Constitution of the United States. DAR Manual for Citizenship published by the National Society, Daughters of the American Revolution, compiled in 1920, revised and updated 1965. Also World Almanac and Book of Facts 1993, Pharos Books.
5. U.S. Code Annotated Title 22 Management of Foreign Affairs. Department of State, Title 22 United States Code, Section 2656, 2656a, 2656b, 2656c, 2656d. Pages 196-208. Defines the responsibilities of the President and Secretary of State involving science and technology agreements.
6. Handbook on Treaties and Other International Agreements. United States Department of State. Chapters 700-750. Codification of Circular 175 Authorization Procedures. Foreign Affairs Manual, Volume II, Section 700. Covers requirements for negotiation, signature and reporting.
7. Circular 175 Authority to Negotiate and Conclude Agreements Regarding OMEGA Navigation System Stations. Internal U.S. Coast Guard Point Paper dated October 1979. Cites numerous references including DOD Implementing references.
8. Procedures for Concluding International Arrangements and Agreements with attachments. U.S. Coast Guard Commandant Instruction 16201.2 dated 15 Feb. 1977. Provides guidance to U.S.C.G. personnel conducting international agreement negotiations. Discusses Circular 175 and Public Law 92-403.
9. Excerpts from ONSCEN's (Omega Navigation System CENter) International Agreement file, 2 January 1990. Concerns the transfer of Circular 175 Authority from the Navy to the U.S.C.G. and history of this and other 175 Authorities from 1976 to the reference date.
10. Charter for the Civil GPS Service Interface Committee (GPSIC), June 5, 1991 and Remarks to the GPSIC Meeting by F. Michael Swiek, Executive Secretary, United States GPS Industry Council, January 25, 1993.
11. Chapter V of the Annex to the International Maritime Organization (IMO), Safety Of Life At Sea Convention 1974 as amended at the 1988 Global Maritime Distress and Safety (GMDSS) Conference and currently under review. International Maritime Organization, 4 Albert Embankment, London SE1 7SR, U.K.
12. IMO Resolution A.666(16) concerning the adoption of world-wide radionavigation systems, continuity and responsibilities. International Maritime Organization, 4 Albert Embankment, London SE1 7SR, U.K.

United States Inter-Agency Agreements

13. Memorandum of Agreement between the Dept. of Defense and the Dept. of Transportation - Civil Use of the Global Positioning System, January 8, 1993.
14. Memorandum of Agreement between the United States Coast Guard and the United States Space Command - Distribution of Navstar Global Positioning System Status Information, February 12, 1992.
15. Support Agreement between the United States Coast Guard and the United States Air Force Space Command - Distribution of Navstar Global Positioning System (GPS) Status Information, 31 July 1992.
16. Memorandum of Agreement between the Federal Aviation Administration and the United States Coast Guard for the Continued Coordination of the Omega Radionavigation Service which may be used by Aviation Users, November 4, 1991.

International Agreements

17. Agreements (5) between the Government of the United States and the Government of Canada for the Cooperation and Joint Use of the Loran-C System of Radionavigation, 1964-1991.

18. Agreement between The Government of the United States of America and The Government of the Union of Soviet Socialist Republics on The Establishment of Joint Loran-C Chayka Radionavigation Systems, May 31, 1988.
19. International Agreement Concerning the Establishment and Operation of the Civil Loran-C Navigation System in North West Europe and The North Atlantic, August 6, 1992.
20. Agreement on an International Programme for the Joint Radionavigation Service in Far Eastern Waters Using Loran-C and Chayka Stations, September 8, 1992.
21. Agreement for the Development of Loran-C in the Mediterranean Area. Terms and Reference for the Establishment of a Policy Group, Brussels, Belgium, February 11, 1993.
22. Principle for Coordination of Operation of the Omega Radionavigation System by an International Omega Technical Commission, December 21, 1981. Renewed June 6, 1990.
23. International Omega Agreements:

    (a) Omega Navigational Station Norway. Agreement Between the United States of America and Norway, signed at Oslo, Norway, November 5, 1971.

    (b) Omega Navigational Station Liberia. Agreement Between the United States of America and Liberia, signed at Monrovia, Liberia, April 10 and 18, 1973. Amendment signed August 16, 1983.

    (c) Omega Navigational Station Australia. Agreement Between the United States of America and Australia signed in Canberra, Australia, June 8, 1977.

    (d) Omega Navigational Station Japan. Agreement Between the United States of America and Japan, signed at Tokyo, Japan, August 15, 1972.

    (e) Omega Navigational Station Argentina. Agreement Between the United States of America and Argentina, signed at Buenos Aires, Argentina, December 4, 1970. Amendment to the Agreement signed at Washington, DC, U.S.A., 24 July, 1992. Supplementary Agreement for the Operation and Maintenance of the Omega Golfo Nuevo Argentine Station signed on March 1, 1988.

    (f) Omega Navigational Station, La Reunion, France. Memorandum of Understanding Concerning the Operation and Maintenance of Omega Station La Reunion between the Government of the United States and the Government of France, signed on June 24, 1981. Logistics Plan for Omega Station La Reunion signed on January 3, 1983.

Plans and Policy

24. Annex 10 To the Convention on International Civil Aviation, Fourth Edition of Volume 1, April 1984 - Amendment 67, Appendix B to Part 1: ICAO ILS/MLS Transition Plan.
25. Federal Register Volume 54, No. 347, Wednesday, December 27, 1989, pages 53231-2: Precision Approach Landing Systems Policy.
26. Report of the GNSS ICAO-FANS Meeting 4-5 February, 1993, CAA House, London, U.K.. GNSS Medium/Long Term Planning, February 1993.
27. Report of the Working Group of the Whole ICAO FANS Committee, London, U.K., 10-18 May 1993. Future Air Navigation Systems Phase II.
28. FAA Satellite Navigation Program Master Plan, FY 93-98, February 15, 1993. U.S. Federal Aviation Administration Research and Development Service, Satellite Program Office (ARD-70).
29. National Air Traffic Services Technology Systems Strategy Paper for Global Navigation Satellite Systems, Civil Aviation Authority, London, U.K., February 1993.
30. FANS Implementation Strategy - An IATA Proposal. 22 December 1992.
31. The International Association of Lighthouse Authorities (IALA) Policy on Radio Aids To Navigation, March 1992. IALA, 20 ter rue Schnapper, 78100 St Germain en Laye, France.
32. Keynote Address: European Economic Community Radionavigation Perspective, Jacques de Dieu, Directorate General for Transport, Commission of the European Communities. Wild Goose Association Annual Convention and Technical Symposium, Birmingham, U.K., August 24-27, 1992.
33. Omega White Paper - Analysis of the Omega and TACAN Radionavigation Systems: Administrator, Research and Special Programs Administration, Chairman DOT Navigation Council, August 6, 1991.
34. United States 1992 Federal Radionavigation Plan Prepared Jointly by the Department of Defense and the Department of Transportation, DOT- VNTSC-RSPA-1992-2 DOD-4650.5, published January 1993. Available from NTIS: phone 1-800-487-4650 or 703-487-4700.
35. RTCA Task Force Report on the Global Navigation Satellite System (GNSS) Transition and Implementation Strategy, September 18,1992. RTCA, Inc., 1140 Connecticut Avenue, Northwest, Suite 1020, Washington, D.C. 20036, U.S.A.
36. The Future of the U.S. Global Positioning System. Statement by U.S. Senator Jim Exon (D-NE), from the floor of the U.S. Senate, April 30, 1993.

Costs and Cost Recovery

37. U.S. General Accounting Office (GAO) Report to the Chairman, Subcommittee on Transportation and Related Agencies, Committee on Appropriations, House of Representatives. Airspace System: Emerging Technologies May Offer Alternatives to the Instrument Landing System, November 1992.
38. U.S. General Accounting Office An Unclassified Overveiw of Defense Satellite Programs and Launch Activities. GAO/NSLAD-90-154FS, June 1990.

39. Navstar Global Positioning System User Charges. Preliminary Report to the Senate and House Committees on Armed Services. U.S. Department of Defense, March 1, 1982.
40. Ariane Rules the Commercial Roost, (Analysis of commercial launch market). Interavia/Aerospace World, January 1993.
41. The Feasibility of Using Small, Low Cost Satellites (Econosats) as an Augmentation to GNSS and as an Eventual Fully Capable GNSS. Keith McDonald and Jim Nussbaum, Sat Tech Systems, Inc., Arlington, VA, U.S.A. and A.J. Van Dierendonck and George Kinal INMARSAT, London, U.K. Paper presented at the Institute of Navigation, National Technical Meeting, San Francisco, CA, U.S.A. January 20-22, 1993.
42. Allocation and Recovery of Federal Airport and Airway Costs, 1991. Office of Aviation Policy and Plans, Washington, DC, U.S.A. FAA-APO-91-4, February 1992.
43. Airport and Airway Costs: Allocation and Recovery in the 1980's. Office of Aviation Policy and Plans, Washington, DC, U.S.A. FAA-APO-87-7, February 1987.
44. The Status of the Airport and Airway Trust Fund, A Special Study by the Congressional Budget Office, The Congress of the United States, December 1988.
45. Airport and Airway Trust Fund. Aviation Policy Office leaflet, July 16, 1992. Descriptive material and update.
46. United States Naval Observatory Daily Time Differences, Series 4 Weekly Bulletin. System Status and Off-Air Times of Omega, Navy VLF, Loran-C, Navy Transit and GPS Systems. U.S. Naval Observatory, Washington, DC 20392-5420, U.S.A. Provides a log of radionavigation system downtime.

Performance Standards

47. International Standards, Recommended Practices and Procedures for Air Navigation Services: Aeronautical Telecommunications Annex 10 to the Convention on International Civil Aviation. Volume 1, Fourth Edition, April 1985 with Amendments up to #68 dated November 15, 1990.
48. Minimum Operational Performance Standards (MOPS) for Airborne Navigation Equipment Using Global Positioning System (GPS) Augmented with Other Systems/Equipment/Techniques. Parts I to VII. RTCA Paper No. 587-92/SC159-385, August 11, 1992. Working Paper Only not yet released for publication RTCA, Inc., 1140 Connecticut Avenue, Northwest, Suite 1020, Washington, DC 20036, U.S.A. Second Draft: May 1993
49. Technical Standing Order: TSO-C129, Airborne Supplemental Navigation Equipment Using the Global Positioning System GPS, December 10, 1992. Department of Transportation, Federal Aviation Administration, Aircraft Certification Service, Washington, DC, U.S.A.

Relevant Written Material by the Author

(a) Hearings before the subcommittee on Coast Guard & Navigation, House of Representatives, 93rd Congress. SN 93-30 pp 336-361, April 1974.

(b) A Review and Applications of VLF and LF Transmissions for Navigation and Tracking, Navigation Vol 21-2 pp 117-133, Journal of the Institute of Navigation, Summer 1974. Presented paper received the 1973 ION Burka Award.

(c) Radio Navigation in North America .... the Next 25 Years. Navigation Vol 22-1 pp 1-15, Journal of the Institute of Navigation, Spring 1975. Presented paper received the 1974 ION Burka Award.

(d) The Essential Role of System Specifications for Global Navigation. Proceedings of the 31st Annual Meeting of the Institute of Navigation, June 1975.

(e) Global Radionavigation - A Challenge to Management and International Cooperation. Presented at the International Navigation Congress, Cambridge, MA, U.S.A. 1976. Navigation Vol 23-4 pp 325-333. Journal of the Institute of Navigation, August 1976.

(f) Developing a Commercial Market for GPS Receiving Equipment. Institute of Navigation Satellite Division, 3rd International Technical Meeting, Colorado Springs, CO, U.S.A., September 17-21, 1990. Subsequently published in GPS World, March 1991, Vol. 2 No.3.

(g) Terrestrial Navaids - Critical Stepping Stones to Satellite Navigation. Wild Goose Association 19th Annual Technical Symposium, Long Beach, CA, U.S.A., October 23-25, 1990.

(h) Politics, Economics and Implementation of Global Radionavigation Systems. Royal Institute of Navigation, Satellite Navigation Meeting, November 1991, London, U.K.

(i) Financial Alternatives for Global Satellite Navigation. European International Space Year, Munich, Germany, April 1992. Subsequently published in GPS World, September 1992.

(j) Global Radionavigation - Heading Towards a United States Monopoly? International Omega Association Annual Meeting, Amsterdam, The Netherlands. August 1992.

(k) A Window of Opportunity for a GNSS. February 1993, to be published.

(l) International Trends and Plans for the Use of Federal Radionavigation Systems, March 1, 1993. A complilation of International Agreements and International Radionavigation Policies. Copy held by Volpe National Transportation Systems Center.

AIRCRAFT OWNERS AND PILOTS ASSOCIATION
500 E Street, SW • Suite 920 • Washington, DC 20024
Telephone (202) 479-4050 • FAX (202) 484-1312

Statement of Steven J. Brown

Senior Vice President
Government & Technical Affairs

Aircraft Owners and Pilots Association

Before the

House Committee on Public Works & Transportation

Subcommittee on Aviation

The Honorable James L. Oberstar, Chairman

Concerning Integration of Satellite Technology
Into FAA's Airspace Modernization Plans

July 28, 1992

Mr. Chairman, my name is Steven J. Brown. I am Senior Vice President for Government & Technical Affairs with the Aircraft Owners and Pilots Association.

AOPA represents the interests of 310,000 individual members who own and fly general aviation aircraft to fulfill their personal and business transportation needs. That is 60% of the active pilots in the United States. AOPA members own or lease 62% of the aircraft in the general aviation fleet.

SATELLITE TECHNOLOGY

We appreciate this opportunity to comment on efforts to integrate satellite technology into FAA's airspace modernization plans. Mr. Chairman, I am pleased to report that significant progress is being made in this area. FAA has a number of ongoing aggressive research and development projects which will lead to capacity and safety improvements. The aviation community through RTCA, Inc. is actively identifying satellite application opportunities and establishing standards that will enable airspace system users to extract operational benefits from the equipment they will purchase. We at AOPA are leaders in each of these areas and our continuing involvement in FAA cooperative demonstration projects is focused on proving the benefits of GPS precision approaches and landings in general aviation aircraft.

It is ironic and revealing to note that satellite technology was barely mentioned, if at all, in the FAA's original National Airspace Modernization Plan. Now, twelve years later, satellite technology clearly holds the most promise for efficient and affordable airspace modernization.

AOPA has long maintained that the FAA should shift away from the ground based design inherent in the NAS Plan and incorporate emerging satellite technology into its current Capital Improvement Plan. Advancing technology has overtaken much of the NAS Plan. This is especially true, for example, with respect to technology such as the Microwave Landing System. For enroute navigation and precision approach technology, satellites represent the way of the future.

Furthermore, our analysis suggests that billions can be saved over the next ten years by redirecting FAA's airspace modernization effort and moving aggressively toward implementation of a system relying on satellites and compatible technology such as LORAN-C.

Congress has responded enthusiastically to our message regarding satellite technology. And the FAA now seems to be moving in the right direction, having officially acknowledged last year that "satellite navigation systems could lead to the eventual phaseout of existing National Airspace System ground equipment while maintaining or improving existing levels of service. In addition, satellite-based navigation systems provide the potential for new navigation and landing service." In its Satellite Navigation Program Plan for FY92 through FY97, FAA also notes other specific benefits of satellite technology:

** Consolidation of navigation functions in a single receiver, thereby enabling the eventual phaseout of older navigation aids at substantial savings;

** Improved safety with reduced separation minimums resulting in increased system capacity;

** Accurate area navigation by using efficient, optimized, user-preferred flight paths;

** Significant reductions in aircraft operating costs through the use of efficient route structures;

** Accurate position reporting to enable uniformly high quality worldwide air traffic management;

** Improved ground and cockpit situational awareness to reduce runway incursion;

** Increased landing capacity with up to Category 1 precision approach service to all runways and airports for all aircraft types, including helicopters.

These are the benefits we have highlighted throughout our longterm effort to advocate increased emphasis on satellite technology. The aviation industry has known that these benefits were possible and that some are already within reach. But we needed some help from Congress to persuade FAA to look forward rather than back.

FAA faces a major management challenge as it attempts to implement the technology it has developed. Mr. Chairman, as you are well aware, FAA is organized as a highly interdependent agency. When new technology is implemented it requires FAA to perform research, conduct demonstrations, specify standards, grant certification, establish procedures, and alter air traffic control methods. If any of these necessary activities are managed poorly or lags seriously behind the others, the technology can not be developed and the users do not receive potential benefits they have invested in. Therefore it is essential that FAA make measurable progress in all these areas at a similar pace and with common objectives.

In the satellite programs, FAA is either behind or struggling to stay "at pace" in a number of critical areas. From our perspective, the procedure development process appears nearly dormant and the pace of air traffic control adjustment to new methods and airspace organization concepts is glacial. I believe FAA risks the devastating legacy of having defined, demonstrated and certified new satellite technologies but failed at establishing procedures and air traffic control policies to enable the benefits of increased system efficiency, capacity and safety.

For example, while FAA has approved GPS for "overlay" use of existing approaches, it has not developed even one new approach procedure to one of thousands of airports that could receive instrument approach guidance for the first time. And FAA has failed previously to develop such procedures for Loran C technology that would offer benefits from the investment in equipment more than 100,000 pilots have made.

The substantial savings and benefits inherent in transitioning to the system of the future are too good to pass up. An early transition will save billions on some of the existing Capital Improvement Plan programs which will be unnecessary or incompatible with the new system.

Significant attention is often paid to the subject of FAA procurement reform. But we suggest that the problems with FAA's modernization programs are not necessarily related to an inability to obtain new equipment. Rather, they are more generally a matter of policy choice and management direction. This is one such area where significant improvement can be achieved through appropriate leadership and policy choices.

THE SAVINGS REALIZED -- AOPA'S "FOUR-FOR-FOUR" ALTERNATIVE

As an alternative to the substantial new taxes on general aviation which the President proposed in his budget plan, AOPA is advocating cuts in four expensive FAA modernization programs. Our "four-for-four" alternative calls for $4 billion in spending cuts from four major FAA programs, all of which are troubled or unnecessary initiatives. Furthermore, each is a component of FAA's $32 billion Capital Improvement Program that would be necessary as originally proposed when satellite technology is exploited. These four programs are the Microwave Landing System, the Long Range Radar replacement program, the Advanced Automation System, and the Area Control Facility program.

In the context of today's hearing, it is useful to look at the potential savings in these four major programs because they clearly illustrate the impact of satellite technology on FAA's modernization plans. While these are among the most obvious savings, they are certainly not the only savings to be realized over the next ten years by redirecting FAA's modernization efforts towards satellites.

Microwave Landing System. Both general aviation and the airlines have balked at the Microwave Landing System, which is the technology put forth in the 1970s to improve upon Instrument Landing Systems for precision approach capability. But the GPS satellite technology of today offers superior and less costly alternatives for future approach guidance to airport runways. As FAA acknowledged recently in Geneva at an international conference on future landing systems, it envisions that MLS procurement (previously projected at 1,250 units) will be cut by as much as 1,000 units -- an 80% reduction.

We believe the only remaining use for MLS is the potential for seldom-needed high precision Category III "autoland" approaches performed by the major airlines at a handful of international hub airports. Abandoning procurement of all but the few MLS units needed for this limited application would save approximately $1.4 billion in federal spending.

Long Range Radar. Using GPS satellite technology and datalink, it will be possible for aircraft to "self-report" their position to air traffic control computers. This capability greatly reduces the need to upgrade existing long range radars. In fact, such a self-reporting system -- called Automated Dependent Surveillance -- is already being tested for air traffic control of trans-oceanic airline flights.

The most prudent course to improve long range surveillance capability is to develop an affordable "ADS like" function for all aircraft that would utilize a satellite-based aircraft position reporting system using datalink. By cancelling the Long Range Radar replacement program, nearly $500 million in federal spending will be saved.

Advanced Automation System. The Advanced Automation System is the $5 billion core of FAA's $32 billion airspace modernization program, and it has symbolized the past cost overruns and poor management which have plagued the NAS modernization plan.

We believe that reduced funding for AAS should be a prudent and productive component of any deficit reduction effort. While we agree with the industry position that the program is necessary and should be continued, the system as designed is overly ambitious and exceeds what is needed or technically feasible given the progress that has been made on satellite technology and air traffic automation in general. The program should be scaled back, and continued appropriations should be carefully metered to ensure that the history of management and technical problems is resolved.

Area Control Facility. The Area Control Facility concept is integrally linked to the Advanced Automation System. ACF has been controversial since FAA first proposed transferring operations from all radar approach control facilities and control towers within a specified region to one remote consolidated site. Recently, the agency announced that it is abandoning plans for massive consolidation down to a mere 23 facilities. Instead, approximately 170 facilities are planned.

By trimming the Advanced Automation System, reducing the scope of the Area Control Facility concept, and realizing further savings in AAS costs, we believe potential federal savings could total as much as $2 billion. Realistically, these much delayed programs will not be deployed until at least the last half of the 1990s.

Again, Mr. Chairman, the $4 billion in savings we estimate from cutting or scaling back these four programs represents AOPA's alternative to imposing future taxes on AOPA members and the general aviation community. But these and other cost savings should be pursued under any circumstances. They illustrate the realistic financial impact of satellite technology on FAA's modernization plans.

SUMMARY

In summary, Mr. Chairman, we are encouraged by the FAA's recognition of the benefits we have highlighted throughout our longterm effort to advocate increased emphasis on satellite technology. Satellites are the way of the future and should be the centerpiece of FAA's modernization initiatives throughout the rest of the century and beyond. We believe FAA must overcome the management challenges identified and must prove its ability to design procedures that "enable" user benefits. We urge the Committee to help keep FAA focused on the need to look forward rather than back. The result will be billions in savings compared with the FAA's original NAS modernization plan.

Mr. Chairman, this concludes my comments. I will be happy to respond to questions from the Committee.

TRIMBLE NAVIGATION LIMITED
WRITTEN TESTIMONY
SUBMITTED BY RALPH F. ESCHENBACH

PROVIDED BY
DR. CLARK E. COHEN AND DR. BRADFORD W. PARKINSON
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
STANFORD UNIVERSITY

The following documents are submitted as written testimony to the Subcommittee on Aviation of the House Committee on Public Works and Transportation for the hearing on "Future Uses of Satellite Technology in Aviation" on July 28, 1993. These documents are submitted by Ralph F. Eschenbach, Vice President, Navigation Division of Trimble Navigation Limited, a manufacturer of innovative precision navigation, positioning, and survey equipment which relies on the U.S. Government-operated NAVSTAR Global Positioning System (GPS). These documents were provided to Trimble Navigation Limited by Dr. Clark E. Cohen and Dr. Bradford W. Parkinson, Department of Areonautics and Astronautics, Stanford University. Dr. Parkinson is a member of the Board of Directors of Trimble Navigation Limited.

These documents provide additional technical information on two of the areas addressed in the oral testimony provided by Mr. Eschenbach: the impact of GPS in navigation and in landing systems.

Real-Time Cycle Ambiguity Resolution using a Pseudolite for Precision Landing of Aircraft with GPS

Clark E. Cohen, Boris Pervan, H. Stewart Cobb,
Dave Lawrence, J. David Powell, Bradford W. Parkinson

Department of Aeronautics and Astronautics, Stanford University
Stanford, California 94305-4085

ABSTRACT

The centimeter-level precision of GPS carrier phase offers the key to precision landing of aircraft with GPS. A new *Kinematic Landing System* (KLS) is presented, wherein carrier phase measurements from a pseudolite (a ground-based, pseudo-GPS satellite) augment real-time kinematic positioning with GPS. *Within seconds, the system resolves the carrier phase cycle ambiguities with extremely dependable results.*

As an aircraft flies over the pseudolite, a large angular geometry change occurs on a time scale of seconds. Considered with respect to the slowly-changing satellite geometry, the pseudolite carrier phase range measurements reveal the cycle ambiguities for each satellite. *Initial flight experiments indicate that robust measurements of altitude can be obtained to within a few centimeters.*

To test the system design, landing approaches were performed in a single-engine Piper Dakota. An L1 C/A code pseudolite was placed roughly 1 km from the threshold, situated along the centerline of the landing strip. The aircraft was outfitted with four GPS antennas on the top-side for position and attitude and a belly-mounted pseudolite receive antenna. Carrier phase measurements from all aircraft antennas and a ground-based reference station antenna were collected and post-processed to resolve the precise aircraft position during landing.

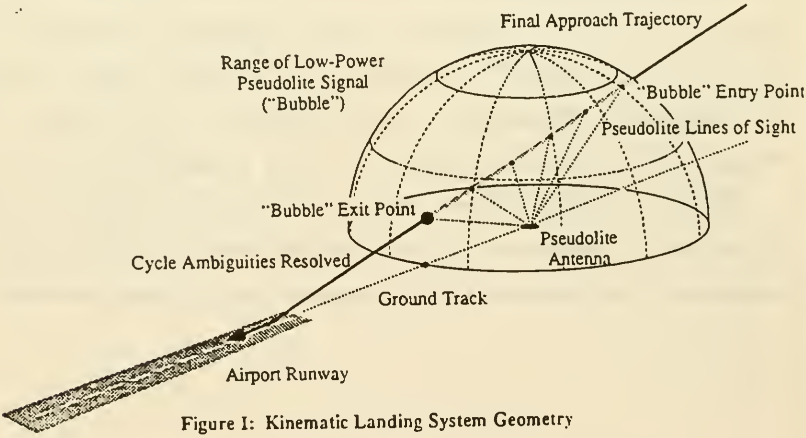

Final Approach Trajectory
Range of Low-Power Pseudolite Signal ("Bubble")
"Bubble" Entry Point
Pseudolite Lines of Sight
"Bubble" Exit Point
Pseudolite Antenna
Cycle Ambiguities Resolved
Ground Track
Airport Runway

Figure I: Kinematic Landing System Geometry

Presented at the Second International Symposium on Differential Satellite Navigation Systems, March 30-April 2, 1993, Amsterdam, The Netherlands.

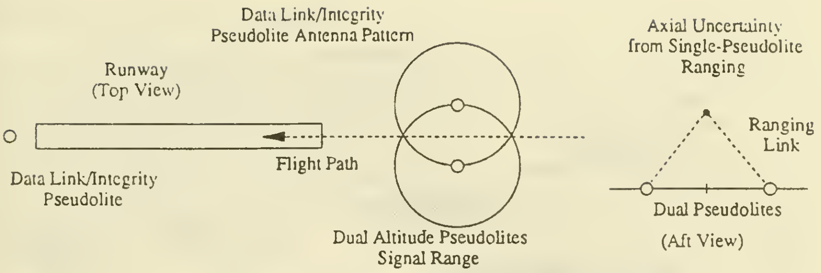


Figure 2: Final Approach from Top and Aft Views

INTRODUCTION

The most stringent category of precision landing (Category III) requires vertical position accuracy of one foot (30 cm). Based on ranging using the L-band carrier of GPS (1.5 GHz, 19 cm wavelength), a state-of-the-art GPS receiver can measure the carrier phase to within a small fraction of a wavelength (a few millimeters RMS). The *Kinematic Landing System* (KLS) presented here provides an extremely robust means for achieving dependable, accurate positioning to within the required specifications.

The centimeter-level precision of GPS carrier phase offers the most promising means for achieving the precision landing requirements using GPS. Such accuracy, however, is subject to the reliable resolution of the cycle ambiguities. The GPS receiver measures the fractional component of phase. The integer component must be obtained through separate means. Once the cycle ambiguities associated with the GPS carrier are initialized, the relative position of two separate antennas can be determined to the centimeter level.

Figure 1 shows the pseudolite (ground-based pseudo-GPS satellite) situated directly underneath the glide slope. The transmitter broadcasts at low power, such that the signal is only received inside a "bubble" whose radius is somewhat larger than the nominal aircraft altitude above the glide slope. As the aircraft overflies the pseudolite, the changing geometry provides the means for resolving the aircraft altitude and along-track position to the centimeter level. Precise positioning with respect to a nearby differential reference station (not shown) is available by the time the aircraft exits the bubble and continues through landing.

Figure 2 extends the concept to two pseudolites situated on either side of the glide slope. As discussed in the analysis section below, a single pseudolite signal provides along-track and radial position. Therefore, the combination of two pseudolites provides all three dimensions of position. At left, this figure also shows a pseudolite data/integrity broadcast transmitter which radiates directionally up along the glide slope. Visible to the aircraft continuously during final approach, this signal is used to transmit data to the aircraft and to provide a redundant ranging link for integrity checking and fault isolation.

The method of using a pseudolite to resolve cycle ambiguities is designed to be extremely robust to ensure dependable operation at all times. Existing methods of cycle ambiguity resolution have relied extensively on having redundant GPS satellites in view.[1,2] It is important to note that the landing system presented here is designed to function perfectly even with the minimum of four satellites in view at a time. Although the GPS constellation design nominally provides six satellites in view at a time, *any viable method of precision landing must still function perfectly even when there are no redundant satellites.*

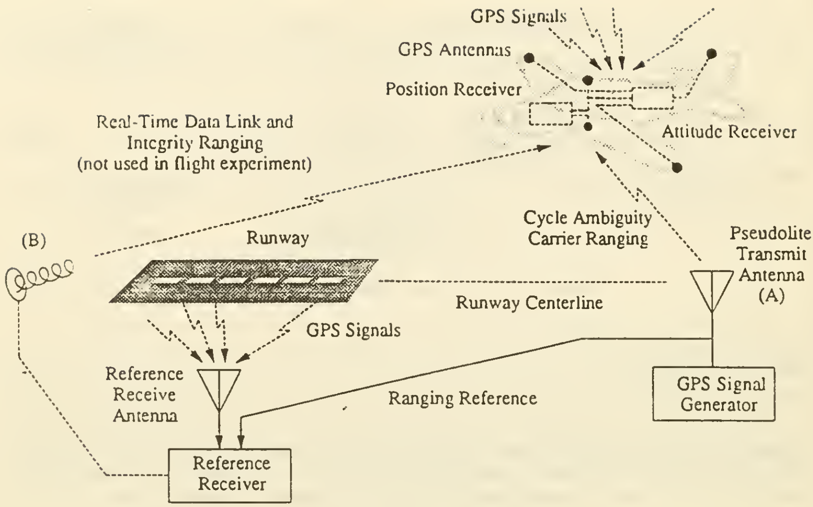


Figure 3: Kinematic Landing System Block Diagram

KINEMATIC LANDING SYSTEM DESIGN

Figure 3 shows the system design for the Kinematic Landing System (for which a patent application has been filed). GPS signals arrive at both the aircraft receiver and the ground-based reference receiver. The GPS signal generator output is broadcast to the aircraft via pseudolite antenna (A). This output is also routed back to the reference receiver on the ground. This ground receiver samples the instantaneous carrier phase of each satellite and the pseudolite and broadcasts these numerical values on a data channel through the pseudolite antenna (B) shown at left. The L-band carrier broadcast from pseudolite antenna (B) also provides a redundant ranging link for integrity checking after the aircraft has exited the bubble.

These transmissions are received by the aircraft position receiver. The aircraft receiver uses the carrier phase measurements of both the pseudolite and the GPS satellite signals—combined with the information in the data link—to resolve the cycle ambiguities and determine its exact position.

Using an unassigned PRN code, the pseudolite (A) broadcasts a signal based either on its own time base or that of the reference receiver. Note that the code phase is not explicitly required for positioning. KLS positioning is completely carrier-based. In fact, the code serves only so that the receiver may distinguish between different GPS satellite carrier signals. *Since code-based ranging is completely optional, it provides an additional, independent layer of integrity checking.*

Four GPS antennas are placed on the top side of the aircraft to measure its attitude. Recent experiments at Stanford and elsewhere have demonstrated the feasibility of using GPS to measure aircraft orientation[3,4] to better than 0.1 deg at 10 Hz.[5] Knowledge of the aircraft attitude aids resolution of the cycle ambiguities. The aircraft attitude is used to apply the lever-arm correction between the top-side antenna used for positioning and the bottom-mounted pseudolite receive antenna. Once the cycle ambiguities are known, the attitude is also used to apply the lever-arm correction for the aircraft landing gear position. Alternatively, attitude information could be obtained from an inertial measurement unit.

OBSERVABILITY ANALYSIS

A simplified analysis of the pseudolite overflight geometry is presented to illustrate how the technique provides both altitude (radial) and along-track position. Figure 4 shows a simple linear trajectory directly over the pseudolite, located at the origin. The aircraft coordinates are along-track position, x, cross-track (lateral, out-of-the-page) position, y, and altitude (radial), z. The magnitude of the aircraft position vector is the range to the pseudolite, r. The single-difference phase, φ, measured between the aircraft receiver and the ground reference receiver is then

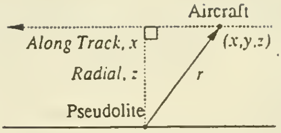


Figure 4: Overflight Geometry

$$\varphi_{aircraft} - \varphi_{ref} = r + b - \Delta t_{aircraft} + \Delta t_{ref}$$

where b represents the sum of the cycle ambiguity and all system biases for the pseudolite ranging link, and each Δt represents each receiver clock bias. Initialized with a trial trajectory from differential GPS, conventional kinematic positioning is used to solve for the relative clock bias between the two receivers. The pseudolite range can then be measured directly, subject to the additive bias, b.

$$\varphi \equiv \varphi_{aircraft} - \varphi_{ref} + \Delta t_{aircraft} - \Delta t_{ref} = r + b = \sqrt{x^2 + y^2 + z^2} + b$$

Linearizing the measured phase about the nominal trajectory which runs directly over the pseudolite (y=0), the nominal observation matrix is given by

$$d\varphi\Big|_{y=0} = \begin{bmatrix} \frac{x}{r} & 0 & \frac{z}{r} & 1 \end{bmatrix} \begin{bmatrix} dx \\ dy \\ dz \\ db \end{bmatrix}$$

For reference, these observation functions (normalized by the radius of closest approach) are plotted in Figure 5 as a function of along track position. As long as the ranging signal is observed over a large enough arc, each observable component of the pseudolite ranging signal is clearly distinguishable, including the most important parameter, altitude.

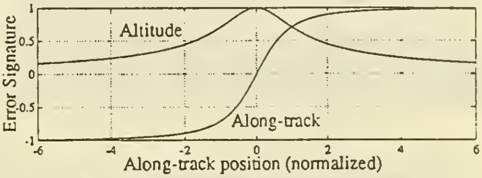


Figure 5: Error Signature for a Pseudolite Pass

Note that the cross-track (lateral) component of position, y, is unobservable with a simple, linear trajectory over the pseudolite. For this reason, the dual pseudolite configuration of Figure 2 is presented. With two pseudolites on either side of the glide slope, all three components of position are directly observable. It may also be possible to obtain the same information from another pseudolite placed under the glide slope of a parallel runway.

EXPERIMENTAL IMPLEMENTATION

To provide an experimental basis for the positioning accuracy claims presented herein, a series of flight tests were performed on a single-engine Piper Dakota both at Palo Alto airport and over the Stanford campus. The experimental campaign consisted of repeated overflights of a single pseudolite.

Figure 6 is a photograph of the aircraft in flight, revealing the four GPS antennas mounted on the fuselage, tail, and each wingtip. Figure 7 shows a close-up of the pseudolite receive antenna mounted on the underside as well as its location with respect the left landing gear.

Cloverleaf Experiment

In the cloverleaf experiment, the pseudolite was situated atop a building on the Stanford campus. The aircraft flew straight-and-level at 1500 ft altitude directly over the pseudolite. The overflight was followed immediately by a 270 deg turn for a repeat pass with a 90 deg heading change. Figure 8 shows a top view of an example trajectory. The reference station is placed at the origin. During the turn, continuous lock was maintained on each the five satellites in view at the time. Using only the raw carrier phase measurements, a batch least-squares fit was used to estimate the Cartesian components of the trajectory, relative clock offset between the airborne and ground reference receivers, the cycle ambiguities (estimated as continuous parameters), and a separate pseudolite range bias (one for each of the two passes). The maximum difference between the estimated cycle ambiguities and the rounded integer values was a tenth of a cycle.

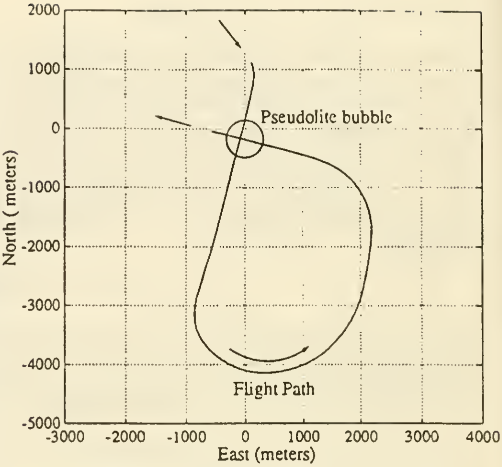


Figure 8: Top View of Cloverleaf Trajectory

To determine if the estimated integers were indeed correct, they were applied to the subsequent leg of the trajectory which included a third, independent pseudolite pass. Since the carrier phase was tracked continuously on five GPS satellites for more than 10 minutes, any error in the cycle ambiguities would become apparent due to the changing satellite geometry. The RMS residual error over the 10 minute span was less than 5mm.

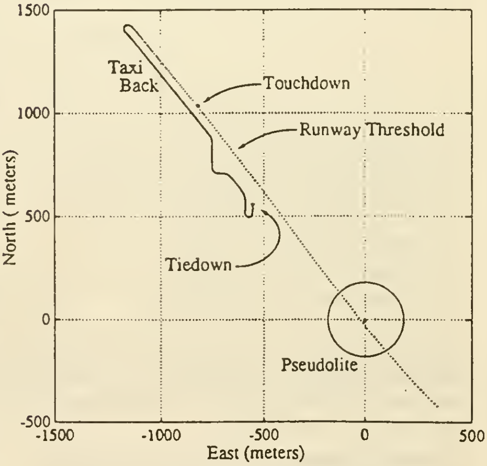


Figure 9: Top View of Landing Trajectory

Final Approach Experiment

In the final approach experiment, the pseudolite was situated 1 km from the threshold directly below the glide slope on final approach to Palo Alto airport. On the last pseudolite overflight of a series of touch-and-go's, the aircraft followed the trajectory shown in Figure 9. Figure 10 shows the measured range from the pseudolite. Continuous lock was maintained as the aircraft landed and taxied to parking. After the flight, a static GPS survey was performed between the fuselage antenna of the aircraft and the reference station. This static survey was then used in post-processing to establish the "truth" values of the cycle ambiguities for the landing.

As described in the observation analysis section above, a linear trajectory over a *single* pseudolite does not provide sufficient information to extract cross-track (lateral) information. For the final landing run, however, there was enough cross-track motion to provide a limited amount of lateral observability.

Figure 3 depicts the experiment hardware. The data/integrity pseudolite link was not employed for the flight experiment. All flight data was analyzed in post-processing. A GPS signal generator running on its own frequency standard supplied the ranging reference (modulated with an unused C/A PRN code). During the test flights, the pseudolite signal was also fed into the reference receiver in order to measure the relative clock offset between the two units. The signal was broadcast from an hemispherical microstrip patch antenna with a 1.5λ radius ground plane. The relative positions of the ground station reference and pseudolite antennas were positioned to the sub-centimeter level using standard GPS surveying techniques.

Three Trimble TANS Quadrex receivers (providing multiple antenna inputs) were used to perform the experiment. One receiver served as the ground reference station, accepting input from both the pseudolite and the GPS satellite signals. The other two receivers were placed onboard the aircraft. The first receiver—connected to the fuselage and belly-mounted antennas—was used for carrier-based ranging for positioning. The second receiver—connected to the four antennas mounted on the top-side of the aircraft—was used for real-time attitude determination. The output of all receivers was recorded on laptop PC's at a 2 Hz rate for post-processing.

Figure 6: Piper Dakota Flight Test Aircraft

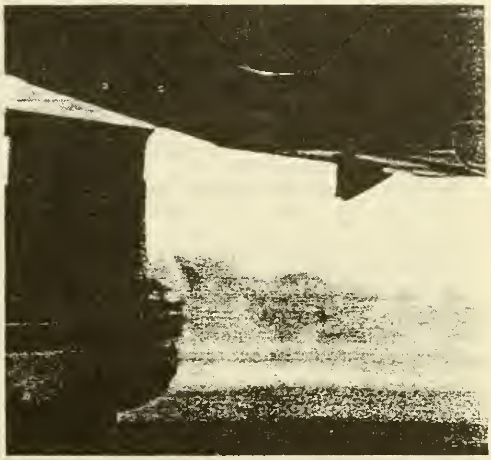


Figure 7: Pseudolite Receive Antenna

The relative locations of the top-side antennas on the aircraft were determined to sub-centimeter accuracy by collecting several hours of static differential GPS carrier phase measurements as the aircraft was parked at the tiedowns. The location of the underside antenna with respect to the other aircraft antennas and landing gear was established using a theodolite.

A simplified model of the troposphere consisted of a flat-Earth, isotropic block of medium with the index of refraction of air, interfacing to a vacuum. This model is valid within at least one kilometer of range from the reference station. Although it was not explicitly required for the 1 km baseline length, the ambient barometric pressure, temperature, and humidity were used to refine the assumed index of refraction, following the formulation of Smith and Weintraub.[6] Ionospheric effects were neglected.

RESULTS

Two specific flight tests were performed: the cloverleaf experiment and the precision landing final approach. Since a single pseudolite is capable of resolving position in two axes, the cloverleaf experiment allows all three components of position to be resolved.

Table 1: Final Approach Results

(cm)	Δ	σ
Radial	4.3	2.7
In-track	2.3	0.9

coupled with excellent along-track and altitude (radial) observability. Therefore, no constraints were imposed on the solution to ensure convergence. Note that the radial axis does not exactly coincide with the vertical direction because the aircraft was descending several meters to the left of the pseudolite.

Table 1 shows the difference (Δ) between the kinematic position based on the known integers and the trajectory based on the pseudolite measurements. Also included is an estimate of the uncertainty (σ). The largest systematic source of error in the entire experiment is thought to be in the independent measurement of the pseudolite receive antenna phase center location on the bottom of the aircraft. The estimated trajectory is shown in Figure 11. The points along the trajectory at which pseudolite measurements were performed are indicated by asterisks.

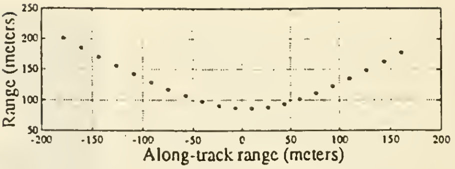


Figure 10: Measured Range to Pseudolite

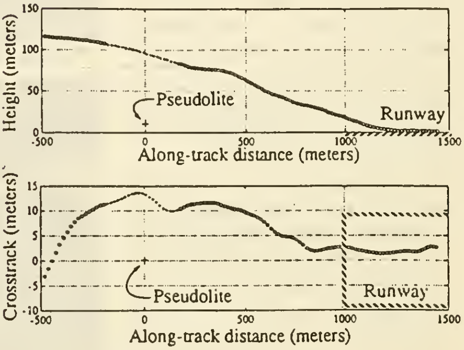


Figure 11: Landing Trajectory

Operational implementation of the system will be enhanced significantly by employing dual pseudolites on either side of the glide path. Flight testing with such a geometry is currently underway.

DISCUSSION AND CONCLUSIONS

Based on preliminary flight testing on a Piper Dakota, the potential for using pseudolites to resolve cycle ambiguities for dependable centimeter-level, real-time positioning has been demonstrated experimentally.

In the Kinematic Landing System presented herein, cycle ambiguities are resolved in real time by taking advantage of the change in geometry that occurs as the aircraft overflies the pseudolite. The system enjoys a number of advantages, including:

- **Robust and Dependable Operation**

The Kinematic Landing System presented here is designed to be exceptionally robust and dependable. With only the basic L1 C/A code GPS service and the 100m level of Selective Availability that has been guaranteed by the Department of Defense, the system is designed to satisfy completely the most stringent specifications on positioning accuracy, including the 30 cm Category II/III altitude requirement.

- **Built-in Integrity Checking**

A number of "safety nets" are available to warn the pilot of any improper operation. The cycle ambiguities (estimated as continuous parameters) can be checked easily to see if they actually converge to *integer* values. Next, the redundant ranging link of the data channel can be used to trap a problem, since the position solution will always be over-determined. Finally, note that the system does not explicitly require code-based ranging at all except for coarse initialization of the least-squares iteration. Therefore, the code may be employed as an independent means to monitor solution integrity.

- A Built-in Data Channel

A key advantage of pseudolites is that they can double as the data channel to uplink differential corrections to the aircraft. By reusing the portion of the RF spectrum allocated to GPS, lower frequencies are available for other purposes.

- Low System Cost

The final key advantage of the Kinematic Landing System is that it is likely to be inherently inexpensive. The hardware for the ground component might cost less than $100K. Since it is based entirely on differential techniques, no exotic ultra-stable clocks or other expensive components are required. Furthermore, both the ground-based and aircraft components of the system are easy to calibrate. The ground system may be installed and calibrated with less than an hour of static GPS survey. Furthermore, the pseudolite receive antenna location on the underside of the aircraft can be exactly determined simply by landing at a KLS-equipped airport and resolving the cycle ambiguities by other means.

ACKNOWLEDGMENTS

At Stanford, the assistance of Yi-Chung Chao, Paul Montgomery, Glenn Lightsey, Konstantin Gromov, Renxin Xia, Denise Freeman, and Tom Langenstein is greatly appreciated. The assistance of Mr. Larry Feltman, Palo Alto Airport Controller, is also greatly appreciated. The authors gratefully acknowledge Trimble Navigation for providing GPS receiver hardware used in these experiments. The Federal Aviation Administration is gratefully acknowledged for supporting the flight tests.

REFERENCES

1. G. Lachapelle, M.E. Cannon, G. Lu, "Ambiguity Resolution On-the-Fly: A Comparison of P Code and High Performance C/A Code Receiver Technologies", ION GPS-92, Albuquerque, NM, Sept., 1992.

2. R. Hatch, "Instantaneous Ambiguity Resolution", *Proceedings of the IAG International Symposium No. 107 on Kinematic Systems in Geodesy, Surveying and Remote Sensing*, Springer Verlag, New York, pp. 299-308.

3. C.E. Cohen and B.W. Parkinson, "Aircraft Applications of GPS-Based Attitude Determination: Test Flights on a Piper Dakota", ION GPS-92, Albuquerque, NM, Sept. 1992.

4. F. van Graas, and M. Braasch, "GPS Interferometric Attitude and Heading Determination: Initial Flight Test Results", *Navigation*, Vol. 38, Autumn, 1991, pp. 297-316.

5. C.E. Cohen, B.D. McNally, and B.W. Parkinson, "Flight Tests of Attitude Determination Using GPS Compared Against an Inertial Navigation Unit", ION Nat. Tech. Mtg., San Francisco, CA, Jan. 1993.

6. E.K. Smith and S. Weintraub, "The Constants in the Equation for Atmospheric Refractive Index at Radio Frequencies", *Proceedings of the Institute of Radio Engineers*, 41 (8) pp. 1035-1037.

Flight Tests of Attitude Determination Using GPS Compared Against an Inertial Measurement Unit

Dr. Clark E. Cohen & Dr. Bradford W. Parkinson
Stanford University
B. David McNally
NASA Ames Research Center

ABSTRACT

Attitude determination using GPS has been applied successfully to aircraft in experiments by a number of researchers. In an effort to formally characterize its accuracy and bandwidth performance, a GPS attitude determination system was flight tested against an inertial navigation unit (INU). *Based on completely separate physical principles, this testing provides an independent means of evaluating overall performance.*

The sub-centimeter relative ranging precision offered by measurements of carrier phase serves as the foundation of attitude determination using GPS. Real-time attitude capability has been demonstrated with an accuracy better than 0.1 deg at an output rate of 10 Hz. Such performance opens the door to new applications in aviation, including heading and attitude sensing to augment traditional cockpit sensors and on-line aircraft system identification to enhance flight safety.

For the flight experiments, a King Air 200 twin turboprop transport aircraft (NASA 701) was outfitted with a Trimble TANS Vector attitude determination receiver. A Litton LN-93 strap-down ring laser gyro INU was operated in the main cabin as the independent reference.

For system evaluation, a number of test maneuvers were executed, including pitch angles to ±30 deg and bank angles to ±60 deg. Performance in moderate turbulence was measured. The impact of structural flexure during aircraft maneuvering was evaluated.

INTRODUCTION

Attitude determination using GPS is based on sub-centimeter precision measurements of GPS carrier phase (λ=19cm). As demonstrated by researchers from JPL,[1] Ohio,[2] and Stanford,[3] the orientation of an aircraft can be determined by measuring the relative positions of multiple GPS antennas mounted to an aircraft structure.

The purpose of the test flight presented herein is to provide a quantitative experimental basis for the kinematic accuracy performance evaluation of attitude determination using GPS. The flight test objective was to conduct maneuvers that would allow evaluation of the limit attitudes and dynamic response of the GPS attitude system.

Smooth push-over-pull-up pitch maneuvers were conducted starting with small pitch angles and increasing to ±30 deg pitch angle. Smooth roll reversals were conducted at 30, 45, and 60 deg roll angles. Steady 360 deg banked turns were conducted at 30, 45, and 60 deg roll angles. Pitch and roll doublets were also conducted to evaluate fast transient response. Attitude data from the GPS attitude system and the INU were recorded in-flight for post-test analysis.

Note that the comparison between two different forms of measurement does not explicitly yield accuracy information beyond the specification of the reference instrument. The INU attitude data are accurate to 0.05 deg rms in pitch, roll, and azimuth.[4]

As an adjunct to the flight testing presented here, a study of the impact of structural flexure was performed. Note that there is no requirement that GPS antennas used for attitude be mounted at the extremities of the aircraft. In general, attitude accuracy increases with antenna separation and so does structural flexure. To evaluate the impact of flexure on attitude determination, it was decided to mount the antennas as far apart as possible.

Presented at the ION National Technical Meeting, San Francisco, CA, January 20-22, 1993

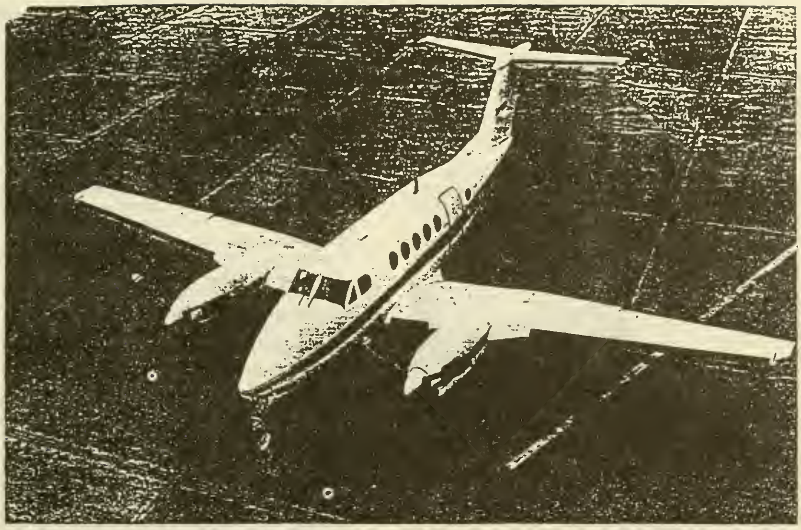


Figure 1: King Air 200 Flight Test Aircraft (NASA 701)

FLIGHT TEST EXPERIMENT ARCHITECTURE

The flight experiment was conducted using the twin turbo-prop transport aircraft (King Air 200, NASA 701) shown in Figure 1.

The GPS attitude system consists of a 6 channel C/A-Code GPS receiver (Trimble TANS Vector) and four microstrip patch antennas. Figure 2 shows a plan view of the antenna installation. The antennas are mounted on the wing tips, the forward fuselage, and on the top of the vertical tail. The four antennas were mounted with their normal vectors aligned, such that they are only translated, *not rotated* (even about the antenna normal) with respect to one another. This installation eliminates any errors due to azimuthal asymmetry of the antenna pattern, because they cancel out in the phase differencing between antennas. Figure 3 shows a close-up of the left wing installation.

The attitude receiver was used as the sensor for the experiments. A 486 laptop computer provided attitude solutions and data recording for post-flight analysis. This combination is capable of providing real-time attitude solutions at an output rate of 10 Hz. However, for the test flights, the computer performed attitude solutions in real-time at a 2 Hz output rate. At the same time, it recorded raw differential phase data at 10 Hz for post-flight analysis.

After the antenna installation was complete, the relative antenna positions were measured with a static "self survey" using GPS. The aircraft was parked in an area free of obstructions to minimize masking and was not disturbed during the survey period. Six and one half (6.5) hours of carrier phase measurements were recorded from

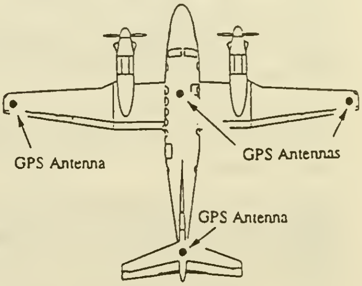


Figure 2: Plan View of GPS Antenna Installation

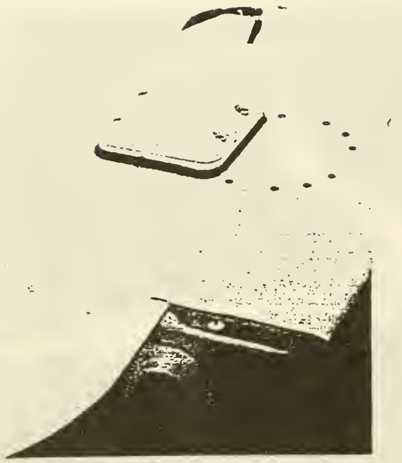


Figure 3: GPS Antenna Installation on Left Wing

the attitude receiver in order to compute a refined estimate of the relative antenna locations. The results are given in Table 1.

Table 1: Relative Antenna Vectors in Body Frame

(meters)	Baseline 1	Baseline 2	Baseline 3
x	6.887	7.702	7.080
y	-8.132	-0.124	8.087
z	-2.719	-1.807	-2.622
length	10.998	7.912	11.064

A strap-down ring laser gyro Inertial Navigation Unit (Litton LN-93) provided reference attitude measurements for comparison with the GPS attitude data. Figure 4 shows a block diagram of the entire test apparatus. The GPS attitude and inertial elements of the test setup are completely independent.

INU data were accessed at 64 Hz via the INU's 1553B data bus, and then time tagged with GPS time before being written to the host computer (68030 VME System) hard disk.

A 1 pulse-per-second (1 PPS) timing signal and its corresponding GPS time, output from a 12 channel P-Code GPS receiver (Ashtech P-12), was used to calibrate the host computer's clock to GPS time. Immediately after reading an INU record, the host computer interrogated the clock and appended GPS time to the INU record.

The GPS time tags on the INU data were the basis for comparison of GPS attitude and INU attitude measurements. It is reasonable to assume that GPS time from the two receivers is consistent to within a few hundred nanoseconds; therefore, this error was neglected.

The INU's 1553 data bus was sampled asynchronously at 100 Hz, giving rise to a 0-10 ms sampling lag (5 ms average). The host computer's time tagging latency was about 1 ms. The INU's 1553 bus latency is estimated to be about 2 ms. Therefore, the total average latency of the GPS time tag on the INU records is estimated to be 8 ms.

The GPS attitude carrier phase cycle ambiguities were resolved in real-time by using the motion-based matrix approach outlined in a previous paper.[3]

Attitude motion (from turns, either on the ground or in the air) is used to determine how many integer wavelengths lie between each pair of antennas in the direction of a given GPS satellite.

Throughout the banks and turns of normal operation, GPS satellites are frequently shaded by the aircraft structure. Once integer lock is initially obtained, it is maintained through an integer "hand-off" from satellite to satellite.

Each time a satellite becomes visible, its integers are automatically assigned based on the current attitude solution that has been computed from the other satellites in view.

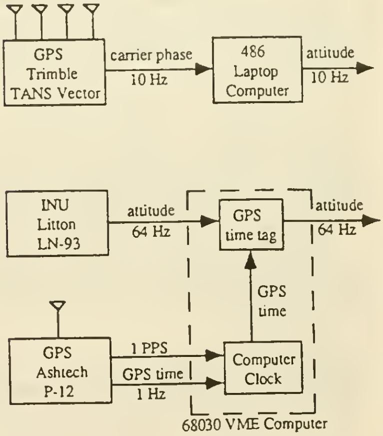


Figure 4: Block Diagram of Experimental Setup

Once the GPS receiver has performed a position fix, only two satellites are required to perform attitude fixes. This capability is based on the *common local oscillator* design of the receiver. As long as at least two satellites are in view at a given attitude, integer lock will be maintained.

Throughout all of the maneuvers performed in the test flight, the attitude receiver lost integer lock only once. The maneuver was a roll reversal from -60 to +60 deg. The integers were reaquired immediately by performing a shallow banked turn, and the identical roll reversal was repeated at a new heading without incident.

DATA ANALYSIS

Each attitude solution is comprised of a four parameter state that includes heading, pitch, roll, and instantaneous wing flex. A diagram of the aircraft body axes, GPS antenna placement, and wing flex states is shown in Figure 5.

The absolute static accuracy of attitude determination using GPS has been demonstrated previously by measurements taken against a stellar reference.[5] Therefore, it is entirely sufficient to align the GPS coordinate frame with repect to the INU using static measurements.

Static calibration data files of approximately one minute duration were collected on the tarmac immediately prior to and immediately following the test flight. The attitude alignment matrix between the GPS receiver and the INU were adjusted until the mean of the static attitude errors using both pre- and post-flight data were zero. This calibration is presented in Table 2.

Table 2: Static Calibration Results
(following application of alignment correction)

Pre-Flight (one minute mean):

(degrees)	GPS	INU	INU-GPS
Heading	-24.62	-24.66	-0.04
Pitch	1.13	1.18	0.05
Roll	0.52	0.51	-0.01

Post-Flight (one minute mean):

(degrees)	GPS	INU	INU-GPS
Heading	1.00	1.04	0.04
Pitch	1.25	1.20	-0.05
Roll	0.45	0.46	0.01

To form the relative error, INU data corresponding to the 10 Hz GPS attitude solution were computed by linear interpolation of the 64 Hz INU data with the 10 Hz GPS time tag. The differences plotted in the Results Section are the INU measurement minus the GPS attitude measurement for each axis of interest.

The latency on the INU time tags (discussed in the previous section) was observed and estimated through analysis of the roll error and roll rate data from the roll reversal maneuvers. The roll error appeared to be well-correlated with the roll rate, suggesting a timing error. From the data, the time latency was estimated to be about 7 ms—the value that was assumed for the processing of the data presented below. This is consistent with the estimate in the previous section.

Structural Flexure

The capacity of GPS to estimate structural deformation adds an additional dimension to attitude determination. Wing flexure (of almost 10 cm steady-state for the King Air) provides a direct measurement of wing loading.

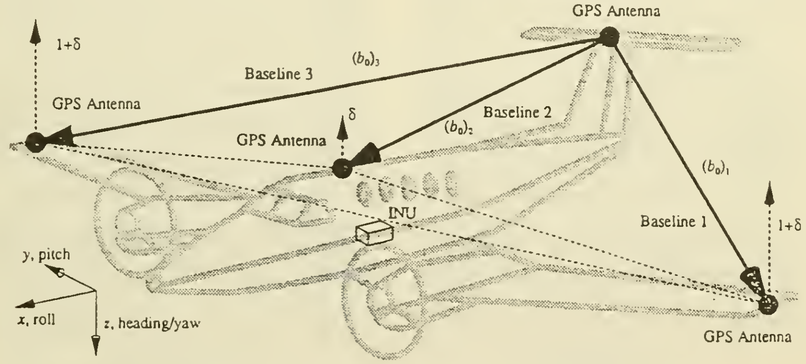


Figure 5: Antenna Baseline and Wing Flexure Definitions

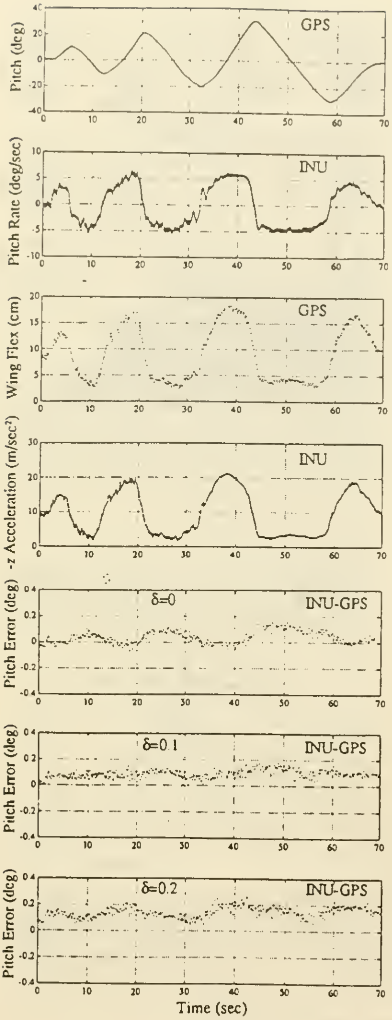


Figure 6: Pitchover Maneuvers

Attitude solutions are augmented with an estimate of the instantaneous wing flexure. The baseline vectors in the body frame of the aircraft are constrained to deform in one particular direction. A given baseline vector, b_0 (3×1), can deform in the direction of b_{flex} (3×1), by a scalar amount, f, as follows:

$$b = b_0 + b_{flex} f$$

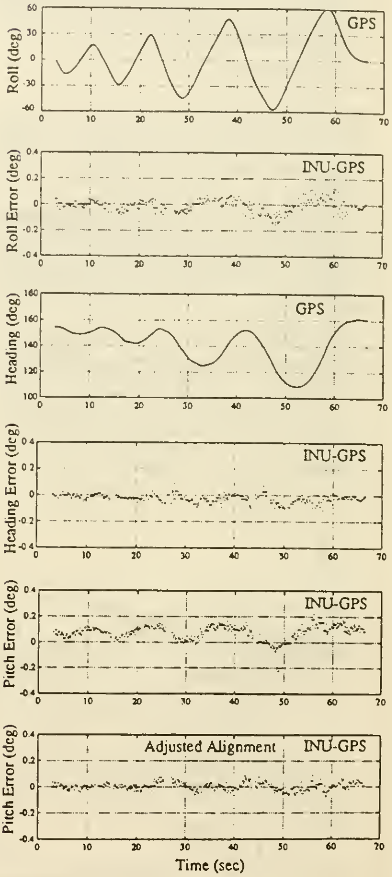


Figure 7: Roll Reversals

The entire set of m baselines is grouped together into a matrix, B, comprised as follows:

$$B = \begin{bmatrix} b_1 & b_2 & \cdots & b_m \end{bmatrix}$$

The matrix of baselines in the body frame are collectively constrained to deform in the direction indicated by the B_{flex} matrix as follows:

$$B = B_0 + B_{flex} f$$

The B_{flex} matrix is formed in an analogous manner to the B matrix. The B_{flex} matrix for the aircraft geometry shown in Figure 5 is given by

$$B_{flex} = -\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1+\delta & \delta & 1+\delta \end{bmatrix}$$

The parameter δ specifies how much the fuselage section of the aircraft deforms during maneuvers. It could also be interpreted as a measure of how wing flexure couples into pitch attitude. For all the results presented herein (except for those in Figure 6), the value of δ was set to zero (the simplest model of wing flexure).

The attitude solution is then given by the 3×3 transformation matrix, A, which rotates the body frame vectors, B, into the local horizontal reference frame to best match the set of n differential phase measurements, φ (n×3), from the GPS satellites. The appropriate cost function to be minimized is

$$J(A,f) = \left\| \varphi_{meas} - \varphi\left[A^T\left(B_0 + B_{flex} f\right)\right] \right\|_2^2$$

RESULTS

The flight test was performed over California's Central Valley on the morning of January 12, 1993. The maneuvers from the test flight (presented herein in chronological order) are

- Static Calibration on Tarmac
- Moderate Turbulence
- Pull-up, Push-down Pitch to 30 deg
- Roll Reversals to 60 deg
- Steady Turn, 45 deg bank, 360 deg heading
- Steady Turn, 60 deg bank, 360 deg heading
- Pitch Doublet
- Straight and Level
- Roll Doublet
- Static Calibration on Tarmac

Some of these maneuvers of particular interest are described here in greater detail.

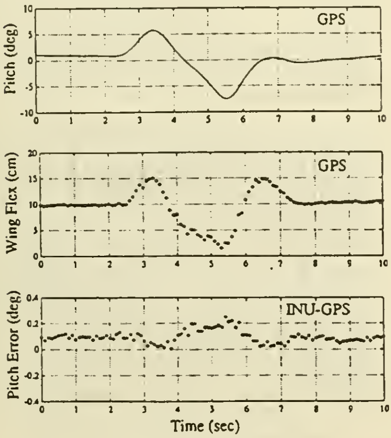


Figure 8: Pitch Doublet

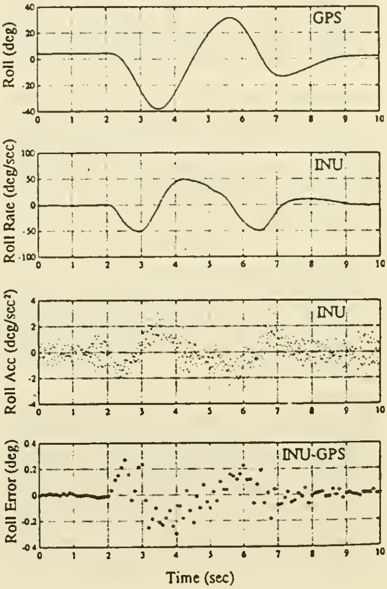


Figure 9: Roll Doublet

Pull-up, Push-down Pitchovers

Figure 6 shows the results of the pitchover maneuvers. The pilots executed pitch angles of ±10, 20 and 30 deg. The pitch rate and vertical acceleration as measured by the INU are plotted immediately following. Since pitch rate corresponds to vertical acceleration, the wing flexure varies in proportion to both acceleration and pitch rate. Note that the structure deforms by almost a full GPS L1 wavelength from peak to peak.

To determine the impact of wing flexure on attitude sensing, the parameter δ discussed in the previous section was varied incrementally in steps of 0.1. Employing any value of δ not equal to zero is equivalent to adopting a more involved model of wing flexure which—depending on the application—may or may not be desirable.

At the normal setting of δ=0, the pitch error is biased from the INU reading by 0.04 deg with a standard deviation of 0.05 deg. However, it is apparent that there is some correlation with the wing flexure state estimate. At a setting of δ=0.1, the agreement between GPS and the INU appears to be independent of wing flexure.

Roll Reversals

Figure 7 shows the results of a series of roll reversals, executed at ±15, 30, 45, and 60 deg. The roll error has a standard deviation of 0.05 deg throughout the entire set. Heading and heading error are also shown for comparison. The controls were coordinated throughout.

The pitch error shows a distinct correlation with the roll angle. This signature is characteristic of an alignment error in heading given (in radians) by the ratio of peak-to-peak pitch disagreement to the corresponding peaks in roll angle. The following plot shows the same pitch error reprocessed, assuming alignment biases of 0.08 deg in pitch and -0.08 deg in heading. The standard deviation drops to 0.03 deg.

Pitch Doublet

The receiver response to transients on a much faster time scale was tested using doublets. In the pitch doublet, elevator control is input in one direction followed immediately by a reversal in the other direction. Figure 8 shows an example of the pitch doublet, including the wing flexure response.

Roll Doublet

Figure 9 shows an example of a roll doublet *with the maximum aileron control authority applied.* The roll excursion traverses 70 deg peak-to-peak in two seconds. The INU roll rate indicates that a maximum roll rate of 50 deg/sec is reached. Roll acceleration is formed by differencing consecutive roll rate measurements. The roll error appears to be a mirror image of the roll acceleration.

The bulk of the discrepancy between GPS and the INU is believed to originate from structural flexure about the roll axis. The ailerons, located near the wing-tips, bend the wings slightly as they accelerate the fuselage in roll. The fuselage lags behind the wings by one or two tenths of a degree in direct proportion to the angular acceleration.

In the case of symmetric bending, such as that from pitch maneuvers or steady, banked turns, wing flexure is completely observable. This is not the case for bending about the roll axis, which couples directly into roll attitude

This pointing discrepancy may or may not be important, depending on the definition of aircraft attitude in the presence of structural flexure. In cases where it is the wing location that is desired, the discrepancy would be attributed to the INU. In applications where fuselage attitude sensing is desired, this plot *places an upper bound of between 0.1 and 0.2 deg on the attitude excursions induced by flexure.* This maneuver is a worst case because *maximum aileron control authority was exercised.*

The 0-10 ms time tagging latency on the INU data introduces an apparent quasi-random error whose envelope is proportional to the attitude *rate*. (See roll error plot)

Summary

A summary of measurement errors for all the maneuvers is presented in Figure 10 and in Table 3.

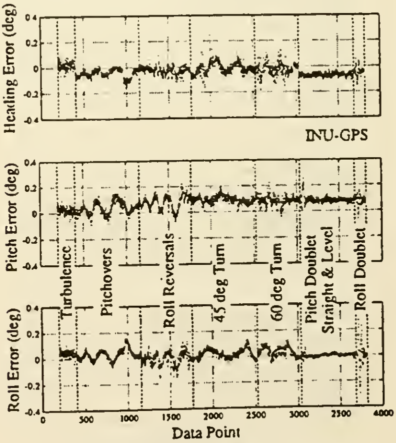


Figure 10: Summary of INU and GPS Differences

The GPS/INU differences are simply concatenated together from each segment of the flight data. In each case, the error is formed by subtracting the GPS measurement from the INU measurement.

Since the plots are shown in flight chronological order, long-term bias trends are also observable. The first segment of data was taken during what the NASA test pilots characterized as "moderate turbulence".

The standard deviation of the disagreement between the INU and GPS was always less than or equal to 0.05 deg—exactly the specification on the INU readout.

Table 3: GPS/INU Comparison Results

Pitch Maneuvers (±10. 20 and 30 deg):

(degrees)	mean	sigma	max
Heading	-0.04	0.03	0.15
Pitch	0.04	0.05	0.16
Roll	0.03	0.04	0.16

Moderate Turbulence:

(degrees)	mean	sigma	max
Heading	0.02	0.03	0.09
Pitch	0.03	0.03	0.10
Roll	0.05	0.02	0.11

Roll Reversals (±15. 30. 45. and 60 deg):

(degrees)	mean	sigma	max
Heading	-0.02	0.03	0.12
Pitch	0.08	0.05	0.22
Roll	-0.01	0.05	0.15

Steady 360 deg Turn (45 deg bank):

(degrees)	mean	sigma	max
Heading	-0.01	0.04	0.15
Pitch	0.10	0.03	0.20
Roll	0.02	0.04	0.14

Steady 360 deg Turn (60 deg bank):

(degrees)	mean	sigma	max
Heading	-0.02	0.05	0.18
Pitch	0.09	0.03	0.23
Roll	0.03	0.04	0.16

Straight and Level, Calm Air:

(degrees)	mean	sigma	max
Heading	-0.06	0.02	0.11
Pitch	0.08	0.02	0.13
Roll	0.00	0.01	0.03

Slowly drifting biases of a few hundredths of a degree appear in the data. The total differences rarely exceeded a tenth of a degree. As mentioned in the above discussion on the roll reversal maneuvers, it appears likely that there is still some residual alignment error between the GPS and INU body reference frames.

SUGGESTIONS FOR FUTURE RESEARCH

The comparison between GPS and INU attitude could probably be improved by a factor of two by carrying out three improvements in the experiment.

- Static Alignment

Performing a longer static measurement before and after the test flight would improve the knowledge of the relative alignment between the INU and GPS reference frames.

- Independent Flexure Measurement

Measurement of fuselage flexure by independent means would clarify the modeling of structural deformation during maneuvers. A simple HeNe laser mounted on the INU bulkhead could sight along the fuselage to a target at the rear of the aircraft.

- INU Time Tagging

Reducing the time tagging latency on the INU data would eliminate the quasi-random element in the comparison data whose envelope is proportional to attitude rates. (See Roll Error in Figure 9.)

CONCLUSIONS

As a commercial passenger transport, the King Air did not appear to possess sufficient aerodynamic control authority to break GPS carrier tracking loop lock with dynamics alone. Nevertheless, the aircraft provides an excellent testing platform on par with flight dynamics rarely encountered in even the most demanding regimes of commercial passenger and general aviation.

Across a wide and strenuous range of large-angle dynamic maneuvers (up to ±60 deg of roll and ±30 deg of pitch), GPS attitude determination performed accurately—even while subject to interruptions and masking of individual GPS satellites due to shading during the course of maneuver execution.

The disagreement between the INU and GPS attitude seldom exceeded a tenth of a degree—even in the presence of structural deformation on the order of a GPS wavelength (19 cm). The standard deviation of the difference measurements did not exceed 0.05 deg for any of the maneuvers. The specification on the INU attitude accuracy is 0.05 deg rms.

Worst case structural deformation about the roll axis due to exercising maximum aileron control authority places an upper bound of between 0.1 and 0.2 deg of roll attitude as the very worst case. Nominal aircraft operation is unlikely to come anywhere near this figure.

APPLICATIONS

The capability of using GPS for attitude determination on aircraft and other vehicles opens up many new applications.

For aircraft operation, GPS offers pilots an artificial horizon and directional indicator that is invulnerable to drift or magnetic variation. The sensor could serve either as primary or backup to the existing complement of sensors carried on aircraft. GPS attitude determination is also likely to play a role in the precision landing of aircraft using GPS, integrity monitoring of GPS, and real-time detection of wind shear.

For aircraft instrumentation, GPS can provide attitude data for remote sensing experiments, flight testing, and aircraft system identification to enhance flight safety.[3]

Applications also extend to space, marine, and land vehicles as a heading and/or attitude sensor or as a means of pointing instrument platforms.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the team of engineers, technicians, test pilots, and support staff at NASA Ames who contributed to the timely design, installation, and flight test evaluation of the GPS attitude system. At Stanford, the assistance of Stewart Cobb is greatly appreciated. The authors gratefully acknowledge Trimble Navigation, Ltd. for providing the GPS receiver hardware used to perform this experiment. At Trimble, the assistance of Marc Crotty, Mike Dentinger, Steve Moore, and Jeff Tonnemacher is greatly appreciated.

REFERENCES

1. G.H. Purcell, Jr., J.M. Srinivasan, L.E. Young, S.J. DiNardo, E.L. Hushbeck, Jr., T.K. Meehan, T.N. Munson, and T.P. Yunck, "Measurement of Aircraft Position, Velocity and Attitude using Rogue GPS Receivers", Fifth International Geodetic Symposium on Satellite Positioning, Las Cruces, NM, March, 1989.

2. F. van Graas, and M. Braasch, "GPS Interferometric Attitude and Heading Determination: Initial Flight Test Results", *Navigation*, Vol. 38, pp. 297-316.

3. Clark E. Cohen and Bradford W. Parkinson, "Aircraft Applications of GPS-Based Attitude Determination: Test Flights on a Piper Dakota", ION GPS-92, Albuquerque, NM, Sept. 1992.

4. LN-93 Standard Ring Laser Gyro Inertial Navigation Unit, Technical Description, Litton Systems, Inc., Guidance and Control Systems Division, 5500 Canoga Ave., Woodland Hills, California. 91367-6698.

5. Clark E. Cohen, H. Stewart Cobb, and Bradford W. Parkinson, "Two Studies of High Performance Attitude Determination Using GPS: Generalizing Wahba's Problem for High Output Rates and Evaluation of Static Accuracy Using a Theodolite", ION GPS-92, Albuquerque, NM, Sept. 1992.

Aircraft Applications of GPS-Based Attitude Determination

Test Flights on a Piper Dakota

Clark E. Cohen
Bradford W. Parkinson

Department of Aeronautics and Astronautics
Stanford University

ABSTRACT

Extensive flight testing has been conducted on a single-engine Piper Dakota to explore new applications of attitude determination using GPS for aircraft. Combined with the navigation function of GPS, real time heading and attitude sensing at 10 Hz to better than 0.1 deg RMS using GPS offers an attractive supplement to existing cockpit instrumentation. *An exciting new application of attitude sensing using GPS is the estimation of the aircraft dynamic model in flight.* Dynamic response data obtained through GPS can be used to estimate aircraft stability derivatives, design optimal autopilots, and augment RAIM. Real time estimation of wing flex using GPS to measure instantaneous wing loading is an added benefit.

Cycle ambiguities are resolved through the natural aircraft attitude motion, consisting of banks, turns, or small attitude motion. *Attitude motion modulates the measurements of GPS carrier phase with a signature that is used to identify the cycle ambiguities within seconds.* Unlike search techniques, the motion-based approach is not vulnerable to false solutions, even for arbitrarily long baselines.

The paper presents and analyzes flight data showing the short-period, phugoid, and Dutch roll modes resulting from impulsive inputs to the controls.

Figure 1: Piper Dakota outfitted with GPS Attitude

INTRODUCTION

Attitude determination is an exciting new application of GPS to aviation. Not only does it offer an efficient and cost-effective real-time heading and attitude reference for the pilot, it has the potential to provide high quality dynamic response data to feed into autopilot design. By applying impulses to the flight controls, a pilot can completely characterize the aircraft dynamics within minutes.

The commonality of GPS receiver hardware used for en-route navigation, precision landing, and attitude implies that *a single GPS receiver could effectively perform the functions of more than half of the cockpit instruments currently in use.*

Sub-centimeter accuracy position measurements of aircraft-mounted antennas are the key to attitude determination using GPS. With potential bandwidth capability reaching well above the dynamics of most aircraft[1] the performance of real-time attitude using GPS is very attractive.

This paper describes the flight test results from the installation of GPS attitude sensing on the single-engine Piper Dakota shown in Figure 1. Four GPS microstrip patch antennas were mounted on the airframe, located on the fuselage, tail, and wing tips. Figure 2 shows a close-up of a wing-mounted antenna.

The Trimble TANS VECTOR attitude receiver was used as the sensor for the experiments. A 486 laptop computer provided both real-time display and data recording for post-flight analysis. The receiver was set to issue measurements at a 10 Hz output rate.

The receiver accommodates up to four antennas for attitude sensing. In addition to providing concurrent GPS positioning, the receiver can be configured to measure carrier beat phase for precision kinematic positioning.

During the test flights over the California coast, a base station receiver was set up at Stanford. The reference

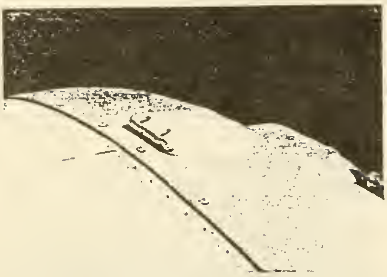


Figure 2: GPS Antenna Mount on Right Wing

measurements were used to obtain precise kinematic position solutions in post-processing as part of the dynamic response testing.

RECEIVER OPERATION

The carrier phase cycle ambiguities can be resolved either on the ground or in the air by using the motion-based approach outlined in the next section. Throughout the banks and turns of normal operation, the GPS satellites in view are frequently obscured. Each time a satellite becomes visible, its integers are assigned based on the current attitude solution that has been computed from the other satellites already in view. For steep angle maneuvers, this "integer hand-off" from satellite to satellite results in seamless operation under dynamics. *Throughout normal operation during the test flights, integer lock was never lost.*

Because the design of the receiver is based on a common local oscillator, *it is possible to perform a complete attitude solution with only two GPS satellites.* The payoff is that the receiver is able to hold on to attitude and integer lock continuously, even during steep angle maneuvers when some satellites become obscured. Although position solutions may be interrupted momentarily, attitude output is unaffected. During the flight tests, the receiver could routinely handle 360 deg turns with a 45 deg bank angle without losing attitude lock.

Each attitude solution is comprised of a four parameter state that includes heading, pitch, roll, and instantaneous wing flex. A diagram of the aircraft body axes, GPS antenna placement, and wing flex states is shown in Figure 3.

The capacity to estimate wing flex is a remarkable facet of the attitude determination problem. Not only does including this state improve the accuracy of the attitude solution (especially in turbulence), some interesting applications result. Most importantly, it provides a real-time indication of wing loading. By scaling the measurement units, wing flex can be converted to g's of vertical acceleration. The result is that *the structural deformation of the aircraft under stress as measured by GPS can be used as an accelerometer!*

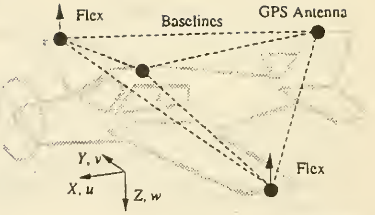


Figure 3: Antenna Placement and Axis Definitions

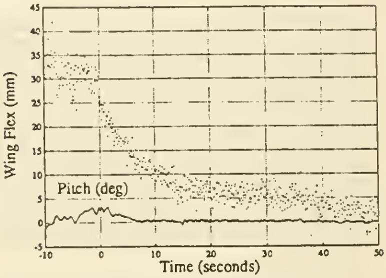


Figure 4: Landing at Half Moon Bay

Wing flex during landing is shown in Figure 4. At the left of the plot, the aircraft is still airborne and undergoing maneuvers that visibly strain the wings. At touchdown, the airspeed and angle of attack drop, and the wings relax to their nominal unstressed displacement. The aircraft finally slows to taxi speed at the far right of the plot.

During nose down (low-g) maneuvers in the Piper test flights, the feeling of weightlessness experienced by the occupants was accompanied by a corresponding reduction in the wing flex readout from GPS.

CYCLE AMBIGUITY RESOLUTION

Cycle ambiguity resolution – the process of determining how many integer wavelengths lie between a given pair of antennas in the direction of a given GPS satellite – is the key bootstrapping step to performing attitude determination. The method used takes advantage of the aircraft angular motion to derive the integer ambiguities in an analytical form.

Previous authors[2,3] have resorted to the integer search approach. In an integer search, different combinations of integer candidates (which can number in the hundreds of millions for antenna separations of even just a few meters) are systematically checked against a cost function until the "correct" set is found.

While many innovative schemes have been synthesized for improving the efficiency of the search process, none of these can possibly address the fundamental liability of their foundation: the search method itself. Its greatest weakness is its propensity to arrive at wrong solutions. The motion-based approach adopted here shares absolutely none of these weaknesses and provides some rather distinct advantages. The key differences are outlined as follows:

1) *Reliability:* Integer search techniques are vulnerable to frequent false solutions. This problem is exacerbated by increasing antenna separation. In the case of the motion-based approach, however, the integers are obtained analytically. It is then very easy to check analytically if there is enough information to resolve the integers rather than having to guess.

2) *Robustness:* The motion-based approach degrades gracefully in situations where the vehicle parameters are way out of specification. (Suppose the host aircraft has been damaged somehow in flight.) Search methods fail altogether in these situations, while the motion-based approach can continue to provide accurate (although partially degraded) results.

The idea behind motion-based integer resolution is to take advantage of the constraints imposed on the differential phase measurements originating from the rigid body mounting of the antennas.

Reference 4 describes a transformation for identifying the integers for a single baseline based on motion. In the following development, this motion-based approach is extended to multiple baselines by including terms associated with cross-correlation of measurements across different baselines. In doing so, a significant limitation of the original method is overcome, namely that *integer resolution is possible with rotation about only a single axis of rotation.*

Without knowledge of the integers, it is possible to determine a position between two antennas relative to an unknown starting point. Since both antennas share a common local oscillator, only three satellites (one for each Cartesian spatial dimension) are required to extract this information.

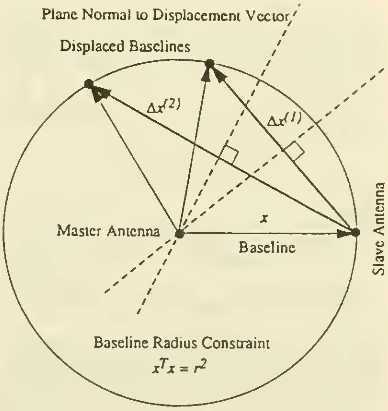


Figure 5: Cycle Resolution using Large Angle Motion

Suppose that a baseline vector, x (3×1), connecting two antennas rotates in space as shown in Figure 5. Since differential positioning is employed, no generality is sacrificed by assuming that the tail of the vector stays fixed. The baseline vector is moved by Δx (3×1) to two different locations at two different times, 1 and 2.

If a plane is constructed perpendicular to each Δx vector passing through its midpoint, note that the center of the sphere must be included in that plane. By simultaneously considering each Δx vector, the center of the sphere can be located and, hence, the initial position, x, of the baseline.

Mathematically, the solution may be developed by constructing the square of the norm of the rotated baseline vector, $x+\Delta x$, given as

$$(x+\Delta x)^T(x+\Delta x) = x^T x + 2\Delta x^T x + \Delta x^T \Delta x$$

Noting that the left side is equal to the square of the baseline length as is $x^T x$, the two terms may be canceled:

$$2\Delta x^T x = -\Delta x^T \Delta x$$

Different Δx vectors taken at n different times (indicated by a superscript) may be stacked as follows

$$2\begin{bmatrix} \Delta x^{(1)T} \\ \Delta x^{(2)T} \\ \vdots \\ \Delta x^{(n)T} \end{bmatrix} x = -\begin{bmatrix} \Delta x^{(1)T}\Delta x^{(1)} \\ \Delta x^{(2)T}\Delta x^{(2)} \\ \vdots \\ \Delta x^{(n)T}\Delta x^{(n)} \end{bmatrix}$$

Then the baseline solution x may be obtained through a linear least-squares fit. Each Δx vector defines a subspace in which the slave antenna must lie. The baseline is then the point which comes closest to this condition in a least-squares sense.

A convenient shorthand notation for this least-squares fit is given by

$$2\,\Delta X^{T} x = -\operatorname{diag}\left(\Delta X^{T} \Delta X\right)$$

where

$$\Delta X\ (3{\times}n) \equiv \left[\Delta x^{(1)}\ \Delta x^{(2)}\ \cdots\ \Delta x^{(n)}\right]$$

and diag( ) corresponds to a vector ($n{\times}1$) comprised of the diagonal elements of the argument ($n{\times}n$).

Unfortunately, large angle rotation about both of the two axes perpendicular to the baseline is *always* required to completely resolve the integer ambiguities. To see this, note that Figure 5 depicts the special case where rotation occurs about only a single axis (the one coming out of the page). The intersection of the planes perpendicular to the Δx vectors is a line rather than a point. Imagine if the true baseline location were actually out of the plane of the page. Given any noise on the measurements, it is difficult to establish the correct perpendicular component of position because the observation matrix is not full rank. Rotation about a single axis does not lend itself to robust cycle resolution.

To address the shortcoming of requiring two-axis motion, it is suggested here that information from multiple baselines be combined into a single simultaneous estimation equation. The idea is to use the constraint equation between different baselines i and j as well:

$$(x_i+\Delta x_i)^T(x_j+\Delta x_j) = x_i^T x_j + x_i^T \Delta x_j + \Delta x_i^T x_j + \Delta x_i^T \Delta x_j$$

Again the dot product of each baseline pair is constant, and the corresponding term may be canceled from both sides. The result is

$$\Delta x_j^T x_i + \Delta x_i^T x_j = -\Delta x_i^T \Delta x_j$$

Combining Δx measurements from n different times, this form may be expanded as follows:

$$\begin{bmatrix} \Delta x_j^{(1)T} \\ \Delta x_j^{(2)T} \\ \vdots \\ \Delta x_j^{(n)T} \end{bmatrix} x_i + \begin{bmatrix} \Delta x_i^{(1)T} \\ \Delta x_i^{(2)T} \\ \vdots \\ \Delta x_i^{(n)T} \end{bmatrix} x_j = -\begin{bmatrix} \Delta x_i^{(1)T}\Delta x_j^{(1)} \\ \Delta x_i^{(2)T}\Delta x_j^{(2)} \\ \vdots \\ \Delta x_i^{(n)T}\Delta x_j^{(n)} \end{bmatrix}$$

Invoking the same matrix notation as above, the entire initial guess for the case of the three baselines shown in Figure 6 can be combined into a single, unified least-squares equation:

$$\begin{bmatrix} \Delta X_2^T & \Delta X_1^T & 0 \\ \Delta X_3^T & 0 & \Delta X_1^T \\ 0 & \Delta X_3^T & \Delta X_2^T \\ 2\Delta X_1^T & 0 & 0 \\ 0 & 2\Delta X_2^T & 0 \\ 0 & 0 & 2\Delta X_3^T \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = -\begin{bmatrix} \operatorname{diag}\left(\Delta X_1^T \Delta X_2\right) \\ \operatorname{diag}\left(\Delta X_1^T \Delta X_3\right) \\ \operatorname{diag}\left(\Delta X_3^T \Delta X_2\right) \\ \operatorname{diag}\left(\Delta X_1^T \Delta X_1\right) \\ \operatorname{diag}\left(\Delta X_2^T \Delta X_2\right) \\ \operatorname{diag}\left(\Delta X_3^T \Delta X_3\right) \end{bmatrix}$$

The left-hand matrix is now $6n{\times}9$, the solution vector is $9{\times}1$, and the right hand vector is $6n{\times}1$. Note that *for small angle motion*, this matrix form reduces exactly to the form developed in Reference 1.

Two important advantages fall out of this approach. First, no *a priori* information about the antenna placement is required to unambiguously solve for all 3 of the three initial baseline vectors (3 components each, 9 total dimensions). Note that it is the measurements themselves that are providing all the geometrical information. Therefore, this approach could be applied to *in-flight self-calibration of GPS antennas.*

Second, for non-coplanar baseline configurations, *a single axis of rotation is entirely adequate for an unambiguous baseline vector solution.* This eliminates most of the dependency on the *type* of motion that the antennas must undergo before there is sufficient information to resolve the cycle ambiguities.

In practice, it likely that the integers will be resolved through static means long before the aircraft engines are turned on. But as a second tier of redundancy, this

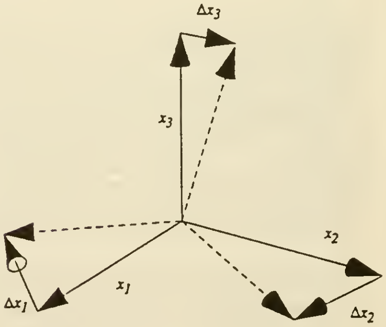


Figure 6: Single Axis Rotation of 3 Baselines

approach allows the aircraft to identify the integers with only a small turn on the taxiway. The integers are practically guaranteed to be known within the first few seconds of taxiing. Once the integers are established, it is rare that they would ever need to be resolved again for the remainder of the flight.

AIRCRAFT APPLICATIONS

Attitude determination using GPS is likely to have a profound influence on aircraft in the future. A partial list of applications is provided here:

- *Heading and Attitude Sensing*

Heading and attitude sensing based on GPS is especially attractive because the readout is immune to drift and magnetic variation.

- *Estimation of Winds Aloft/Wind Shear Detection*

When combined with GPS ground velocity and pilot airspeed, attitude holds the key to providing instantaneous vector measurements of winds aloft. This capability is useful not only for aiding route planning but also as a means for detecting downdrafts or wind shear upon takeoff or landing.

- *Precision Landing*

The precision landing problem using GPS implicitly requires attitude sensing. For kinematic positioning at the sub-meter level, knowledge of the landing gear position is the principal focus, not knowledge of the GPS antenna position.

- *System Identification and Autopilot Synthesis*

A new and exciting application of attitude determination is using it to identify the aircraft dynamic model. The idea is that a pilot can supply inputs to the controls that excite a dynamic response. This response can be measured quantitatively with GPS and used to reconstruct an accurate model of the aircraft dynamics. The model then serves as the foundation for optimal autopilot synthesis.

- *Receiver Autonomous Integrity Monitoring (RAIM)*

Extending the system identification idea further, it is possible that model estimation can be carried out continuously in flight. Furthermore, should any off-nominal conditions arise – either with the GPS system or the aircraft itself – the system could warn the pilot immediately.

In effect, the dynamic model adds a new set of constraints to the position fixes performed by the navigation equipment. These contraints provide an additional line of defense against a variety of GPS positioning failure modes, leading to an overall improvement in GPS system integrity.

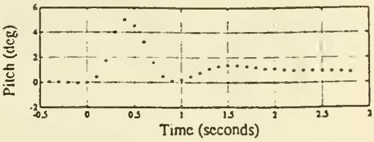


Figure 7: Short Perind Mode Impulse Response

DYNAMIC RESPONSE RESULTS

In the Piper flight tests, position and attitude data were collected in response to impulsive inputs to the elevator and rudder. After the impulse was applied, the controls were left free.

Initial efforts focus on the longitudinal dynamics of the aircraft. The elevator input excites two distinct oscillatory modes of aircraft dynamics: the short period mode and the phugoid mode.

The short period mode consists predominantly of pitch attitude dynamics as the tail acts to align the aircraft into the wind. On the Piper, the short period transient is over after only a couple of seconds. Figure 7 shows an example of the short period mode. Note the 10 Hz sampling rate and the frequency content of the signal being tracked.

The phugoid mode, a slow, periodic exchange between kinetic and potential energy, lasts much longer. Its period for the Piper at nominal cruising speed is about half a minute. The phugoid is predominantly a translational mode, although the pitch attitude generally corresponds to the flight path angle. It is generally lightly damped and can persist for quite a few minutes before settling out.

Figure 8 shows a sample of the phugoid mode data. The first plot shows the pitch angle of the aircraft plotted versus time. Kinematic positioning measurements also reveal the relative altitude and along track position. The along track relative position was obtained by subtracting out the constant velocity component of position. Last, the instantaneous wing flex is shown with a remarkable accuracy of 1.4mm RMS. This figure shows the subtle aeroelastic strain on the aircraft structure induced by the natural dynamics of the phugoid mode.

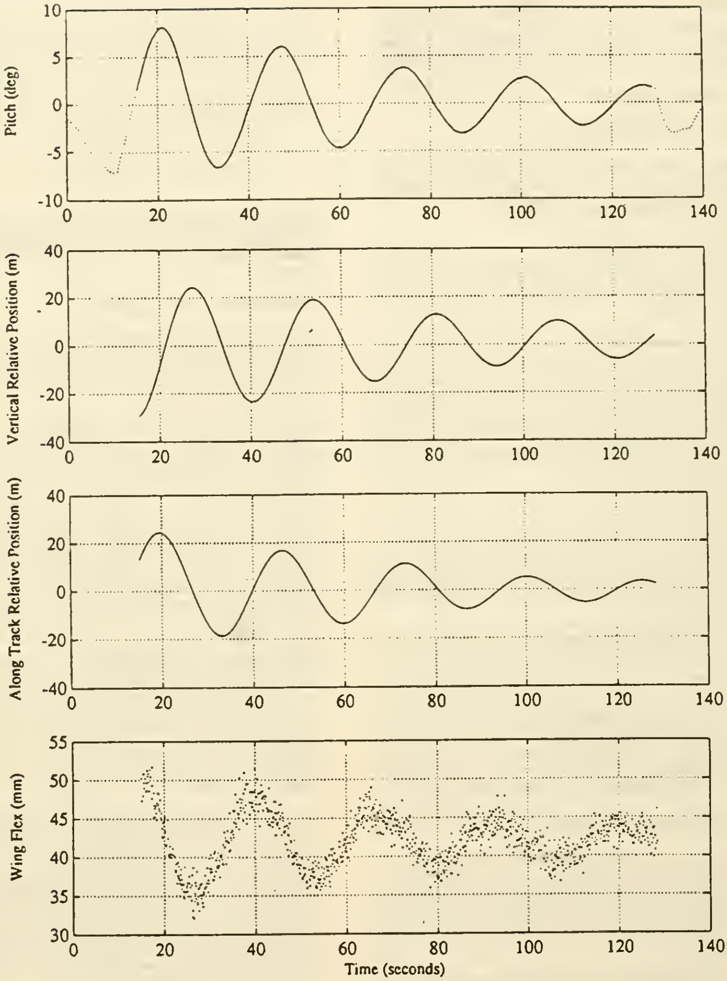


Figure 8: Piper Dakota Phugoid Mode State Estimates

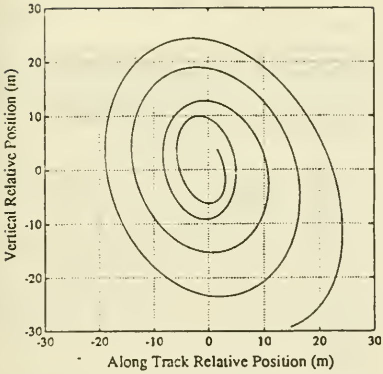


Figure 9: Phugoid Mode Relative Position

Kinematic positioning also enables the construction of the relative position plot shown in Figure 9. This spiral trajectory is the view that would be seen from another aircraft flying parallel, straight, and level.

These phugoid plots – along with the other impulse responses – contain a wealth of information regarding the aircraft dynamics. Table 1 provides the natural frequency, ω_n, and damping, ζ, for each mode.

Table 1: Piper Dakota Longitudinal Modes

Indicated Air Speed:	120 knots
Altitude:	7500 ft

mode\parameter	ω_n (rad/sec)	ζ
short period	6.32	0.41
phugoid	0.236	0.063

A phasor (eigenvector) diagram of the measured parameters of the phugoid is shown in Figure 10. This diagram shows the relative phases of the altitude, h, the altitude rate, $\dot{h}$, the along track position and velocity, x and u, respectively, the pitch angle, θ, and the wing flex.

Even from an elementary consideration of conservation of energy, one can obtain a coarse approximation for the aspect ratio of the phugoid spiral. This argument suggests that the classical spiral should be taller than its width by a factor of $\sqrt{2}$. The experimental value comes out to be quite reasonable at 1.3.

More accurate derivations of the dynamic response are based on the stability derivatives of the aircraft.[5] Each stability derivative is a sensitivity parameter describing, for example, how a moment or force on the aircraft changes with respect to a particular state variable. From the aircraft equations of motion, the natural frequency and damping of the phugoid mode can be expressed as

$$2\zeta\omega_n = -X_u + \frac{M_u(X_\alpha - g)}{M_\alpha}$$

and

$$\omega_n^2 = -\frac{g}{U_0}\left(Z_u - \frac{M_u}{M_w}Z_w\right)$$

where g is the Earth's gravitational acceleration, U_0 is the nominal unperturbed airspeed, and the other parameters are stability derivatives of forces (X and Z defined in Figure 3) and the pitch moment, M, with respect to small changes in airspeed (u and v in Figure 3) and angle of attack, α.

In many cases it is possible to simplify these expressions. For the Piper Dakota, it appears that the second term in the expression for natural frequency is neglectable. Furthermore, it is possible to apply the standard subsonic approximations by assuming that the change in coefficient of lift is independent of u and that Z_u is given by setting the trimmed lift and weight equal. The resulting expression for natural frequency becomes

$$\omega_n = \sqrt{2}\frac{g}{U_0}$$

This result matches the GPS experimental data to within a few percent. But what is extraordinary is that through this relation, *GPS measurements alone are sufficient to make estimates of both airspeed and ground speed without the use of any other sensor.*

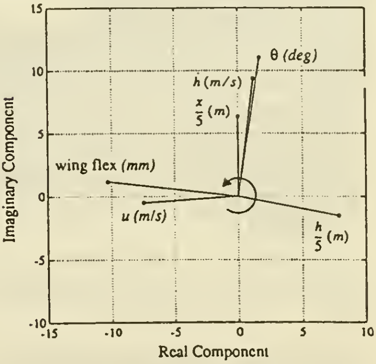


Figure 10: Phasor Diagram of Phugoid Mode

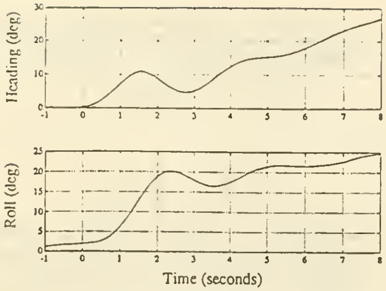


Figure 11: Dutch Roll Mode Impulse Response

Other information about the stability derivatives can be obtained from the relative amplitude and phase of the observable quantities. For example, the phase difference between u and θ yields the ratio of pitch moment stability derivatives:

$$\angle\left(\frac{-\theta}{u}\right) = \tan^{-1}\frac{\omega_n\sqrt{1-\zeta^2}}{\zeta\omega_n + (g M_u / M_\alpha)}$$

GPS attitude sensing also provides a wealth of information on the lateral dynamic modes as well. Figure 11 shows the aircraft response to a rudder kick. The Dutch roll mode is clearly seen as an interchange between roll and heading angles. It also appears that the spiral divergence mode has been excited.

SUMMARY

The availability of high fidelity measurements of attitude and position from GPS offers the unique possibility of easily performing aircraft dynamic model estimation. Given the relatively low cost of receiver equipment, it appears that even continuous, real-time estimates of dynamic parameters is feasible. The end result is more efficient autopilots and safer air travel.

CONCLUSION

An advanced GPS attitude determination receiver has been developed with an output rate of 10 Hz and accuracy better than 0.1 deg for a 3 m baseline. This receiver was flown in a single engine Piper Dakota for extensive flight testing.

Cycle ambiguities are resolved for aircraft applications by taking advantage of the motion of the antenna array during single-axis turns on the ground or banked turns in the air.

An efficient approach to estimating the integers is presented whereby relative position vectors derived from raw measurements are stacked into a system of linear equations in 9-space.

Estimation of wing flex to an accuracy of 1.4mm is demonstrated as a method for obtaining instantaneous wing loading. Such accurate positioning with GPS effectively uses the structural deformation of the aircraft under stress as an accelerometer.

The applications of GPS-based attitude determination to aircraft are explored. The aircraft dynamic model is estimated using GPS exclusively..

The period of the phugoid mode is used to obtain an estimate of *airspeed* derived exclusively from GPS.

The possibility of using GPS to continuously estimate dynamic parameters is explored as a means for improving efficiency and safety.

ACKNOWLEDGMENTS

Special thanks go to Professor J. David Powell of Stanford's Department of Aeronautics and Astronautics for providing his Piper Dakota and skillful piloting for these flight tests. The assistance of Stewart Cobb is also greatly appreciated.

The authors gratefully acknowledge Trimble Navigation, Ltd. for donating the GPS receiver hardware used to perform these experiments.

REFERENCES

1. C.E. Cohen and B.W. Parkinson, "Expanding the Performance Envelope of GPS-Based Attitude Determination", ION GPS-91, Albuquerque, NM, Sept., 1991.

2. R.A. Brown, "Instantaneous GPS Attitude Determination", IEEE PLANS 1992, Monterey, CA, March, 1992.

3. F. van Graas, and M. Braasch, "GPS Interferometric Attitude and Heading Determination: Initial Flight Test Results", *Navigation*, Vol. 38, pp. 297-316.

4. R. Brown and P. Ward, "A GPS Receiver with Built-in Precision Pointing Capability", IEEE PLANS, Las Vegas, NV, March, 1990, pp. 83-93.

5. D. McRuer, I. Ashkenas, D. Graham, *Aircraft Dynamics and Automatic Control*, Princeton Univ. Press, Princeton, 1973.

KGLS TECHNIQUE SHARPENS GPS ACCURACY

PHILIP J. KLASS/WASHINGTON

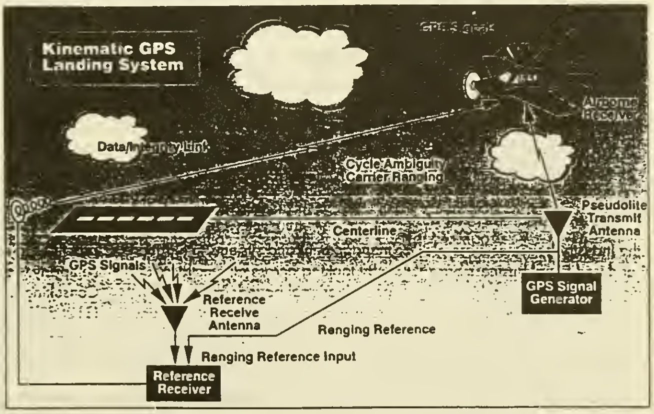
A new technique recently demonstrated by Stanford University scientists could increase the accuracy of the Global Positioning System (GPS) enough that it possibly could be used in Category-3 instrument landings.

The Stanford flight tests indicate the new technique—called Kinematic GPS Landing System or KGLS—can determine aircraft altitude to within 1 ft., according to Clark E. Cohen, who heads the Stanford team that developed the technique. The tests were conducted using GPS receivers provided by Trimble Navigation, Ltd.

Experimental verification was obtained in flight tests recently conducted at the Palo Alto, Calif. airport, which were funded by the FAA. The tests were conducted using the same Piper Dakota earlier outfitted to demonstrate use of GPS satellite signals and interferometry techniques to measure aircraft heading and attitude to better than 0.1 deg. (*AW&ST* Nov. 30, 1992, p. 52).

KGLS extends the capability of differential-GPS (D-GPS), in which local area corrections are transmitted to aircraft receivers, and is expected to provide sufficient accuracy for Category 1 instrument approaches. But its projected vertical accuracy of about 10-15 ft. is not adequate for lower visibility Cat. 2 and Cat. 3 conditions, which require accuracies of 6 ft. and 2 ft., respectively.

Conventional civil GPS receivers use the pseudo-random noise (PRN) code signals emitted by GPS satellites to obtain an unambiguous measure of the distance to each of four or more satellites from which aircraft position and height can be calculated. For civil users, this provides an accuracy of about 100 meters (300 ft.) or about 3-5 meters (10-15 ft.) if corrected with local-area D-GPS.



A new carrier phase tracking technique for enhancing GPS accuracy uses a ground reference station and pseudolites to radiate GPS-like signals.

The improved accuracy of KGLS is obtained by means of phase measurements of the 1.5 GHz. carrier frequency on which the coded signal is modulated. Such carrier phase tracking techniques are being used for land surveying applications where the GPS receiver can remain fixed for an extended period of time to resolve what is called "integer cycle ambiguities."

RESOLVING CYCLE AMBIGUITY is possible because of Doppler shifts in the carrier frequency of each GPS signal created by each satellite's orbital motion relative to a fixed GPS receiver antenna. But resolving such cycle ambiguities from a moving aircraft is much more challenging because of the difficulty of distinguishing Doppler shift due to aircraft motion from that caused by satellite motion.

The Stanford University technique does this by using ground-based "pseudolites, which radiate low-level GPS-like signals, together with a ground-based reference station which receives signals from both GPS satellites and pseudolites.

Current thinking is that in an operational configuration, two pseudolites would be located along the approach path, situated possibly 1-2 km. from runway threshold, while a third pseudolite might be located near the far end of the runway. During the initial portion of an aircraft's instrument approach, it would use conventional D-GPS (PRN code) to determine its approximate location and altitude.

As the aircraft approaches the dual pseudolites, it would acquire their signals enabling it to make the transition to more accurate carrier-phase tracking for the final portion of the approach. The rapid change in the angle from which the aircraft receives the pseudolite signals results in a rapid change in the Doppler shift of their carrier frequencies compared to the Doppler shift of signals from GPS satellites.

Simultaneously, the ground reference station is receiving signals from the pseudolites with no Doppler shift, as well as from the GPS satellites. Because the geographic location of the ground reference station has been established precisely and it can track GPS satellites for an extended period of time, the ground reference station can readily measure the carrier phase information needed by the aircraft to resolve cycle ambiguity.

This information would be transmitted via a third pseudolite at the end of the runway, using the data link capability contained in the GPS signal code. This enables the aircraft to make the transition to carrier phase tracking and accurately calculate its position relative to the ground reference station, and hence to the runway. The third pseudolite signal also provides a redundant means for the aircraft to determine its distance from the runway.

COHEN NOTES that previous concepts for resolving the cycle ambiguity problem from aircraft in flight required that at least five, and preferably more, operational GPS satellites be within view whereas the Stanford technique requires only four.

Although the aircraft would use carrier-phase tracking for the final portion of the approach and landing, the less accurate PRN code could be used to provide a semi-independent means of verifying the integrity of guidance obtained from carrier-phase tracking.

In the recent feasibility demonstration flight tests, the aircraft was not outfitted with the necessary computation capability to determine aircraft position in real time. Instead, the data was recorded for subsequent processing on the ground.

The next phase in the Stanford program calls for developing the required real-time data processing capability for flight test demonstration. Cohen said he hopes to be able to demonstrate real-time accuracies of "a few tens of centimeters" corresponding to about one foot.

For the carrier-phase tracking part of the tests, the Piper Dakota was outfitted with a Trimble TANS Quadrex GPS receiver which was connected to a belly-mounted GPS patch antenna and another antenna installed atop the fuselage. This same topside antenna, plus two others installed on the wing tips and a fourth on the vertical stabilizer, feeding a second Trimble TANS receiver, were used for GPS attitude determination in real-time. A third Trimble receiver was used in the ground reference station.

For the initial flight tests, a single pseudolite transmitter was located 1 km. from the runway threshold. This made it possible to measure aircraft altitude and distance to threshold, but not cross-track deviation. More recently Stanford has installed a second pseudolite to measure cross-track position.

Multipath GPS signal reflections from buildings can cause errors of several feet when the PRN-coded signals are used to determine aircraft position and height. However, when carrier phase tracking is used, the errors caused by multipath are greatly reduced, according to Cohen. Techniques to minimize multipath effects have been developed, but these will increase the cost of GPS receivers.

It is still premature to estimate the cost of outfitting an airport or an aircraft with a kinematic GPS system capable of providing Cat. 2/3 capability and to compare the cost with that of installing MLS. ■

FILTER CENTER

COMPILED BY BRUCE D. NORDWALL

A LITTON AND ROCKWELL COLLINS TEAM will provide the embedded GPS Inertial Assembly (GINA) to the Navy for its T-45 trainer aircraft (*AW&ST* Apr. 26, p. 61). Under a $27.8 million contract, five GINA systems will be supplied to the Navy for tests starting in October. McDonnell Douglas plans to integrate GINA into the T-45 as part of its "Cockpit 21" glass cockpit upgrade. A decision on full production for 250 systems is due in January, 1995. ■

THE AIR FORCE WANTS TO BOOST wafer scale signal processing throughputs by more than order of magnitude, to 20 gigaflops/board, by integrating hybrid wafer scale packaging technology with government-furnished high performance signal processors. Proof of the 30-month effort is to be a real-time demonstration of multi-chip modules in flow-through cooled SEM-E boards integrated into a Sun workstation and C-band radar at the Rome Laboratory. Contact Rebecca Willsey (315) 330-7681. ■

FRANCE'S SEXTANT AVIONIQUE WILL PROVIDE head-up displays (HUD) for operational evaluation on a Northwest Airlines 747 and DC-10, beginning in about two years. Northwest, which also plans to evaluate infrared and millimeter-wave radar as enhanced visibility aids during adverse weather, is negotiating similar contracts with Loral's Fairchild Div. for two FLIR systems and with Lear Astronics for two millimeter-wave radars. ■

A DISSENTING NOTE ON THE UTILITY OF FLIR SENSORS for adverse weather was sounded by Capt. Joseph Oliver, who heads the Air Line Pilots Association's all-weather flying committee, during recent Worldwide Communications, Navigation and Surveillance Symposium. Oliver said tests indicated that current FLIR sensors could not consistently penetrate rain and fog, prompting him to conclude, "We should not depend too heavily on the availability of enhanced visibility systems in the immediate future." ■

A NEW TECHNIQUE DEVELOPED at Georgia Institute of Technology could permit chemical vapor deposition of some thin films without the need for the costly vacuum chambers and furnaces used for conventional chemical vapor deposition. Combustion chemical vapor deposition (CCVD) dissolves the materials to be deposited in a flammable organic solvent such as xylene or toluene. The solution is sprayed with air as a fine mist across a propane torch, which causes the flammable mixture to burn, depositing a film on nearby objects to be coated. CCVD has deposited yttrium-barium cuprate films used for high temperature superconductors and yttrium-stabilized zirconia used for wear-resistant and thermal barrier coatings. ■

DALLAS/FT. WORTH INTERNATIONAL AIRPORT will be outfitted with a Differential GPS terminal to enable the FAA and American Airlines to evaluate the utility of DGPS as a potential Category-1 precision approach aid. Another potential site for DGPS evaluation is the Juneau airport where nearby mountains pose a challenge for adverse weather approaches. Whittman Regional Airport, Oshkosh, Wisc., plans to have a Trimble Navigation Inc., DGPS installation available for test under VFR conditions during the annual Experimental Aircraft Association fly-in starting July 29.

GPS ATTITUDE SENSING TESTED

ALBUQUERQUE, N. M.

Stanford University researchers say in-flight tests they have performed with a Piper Dakota show that GPS can be used to determine aircraft attitude.

They also have concluded that a single GPS receiver could replace the functions of more than 50% of current cockpit instruments.

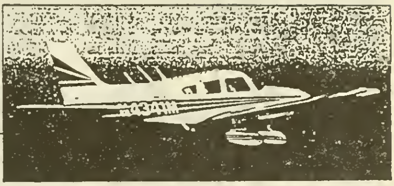
USING GPS for attitude measurements would give flight test programs a new tool. In a surprising side benefit, Stanford researchers discovered that GPS gave accurate measurements of the flexing of wings in flight. The result is that the structural deformation of the aircraft under stress as measured by the GPS can be used as an accelerometer, according to aeronautics and astronautics professor Bradford W. Parkinson.

Four GPS microstrip patch antennas were mounted on the Piper Dakota—one on each wingtip, one on top of the fuselage and one atop the vertical tail.

The tests put to rest one of the reputed stumbling blocks to GPS-determined attitude—that GPS data would be lost when the aircraft maneuvered. Usually five satellites are visible to the antennas, and four are required to determine position in three dimensions. But test data showed that even if several satellites were blocked by the aircraft during maneuvers, only two were needed for a complete attitude solution. Throughout the tests, the antennas always had at least two satellites in view, even during steep maneuvers. The receiver handled 360-deg. turns with 45-deg. angle of bank without losing attitude lock.

A TRIMBLE TANS VECTOR attitude receiver was used as the sensor for the experiments, with a 486 laptop computer providing both real-time display and data recording for post-flight analysis. The receiver was set to take measurements at a 10-Hz. rate. Knowing the placement of the antennas on the wings to sub-centimeter accuracy is necessary to obtain accurate attitude readings.

With the advanced GPS receiver used in the test in a 3-meter receiver baseline, accuracy of better than 0.1 deg. was realized. Wing flex was estimated to 1.4 mm.



Stanford University's Piper Dakota is outfitted with a small, flat GPS receiver on each wingtip, the top of the vertical stabilizer and over the cockpit.

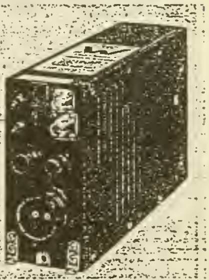
Using GPS to sense heading is attractive because it is not subject to magnetic variation. GPS has a similar advantage for sensing attitude because it does not suffer from the drift of an inertial system or the precession of a spinning gyro.

The flight tests used impulse inputs to the elevator and rudder to evaluate the dynamic response of the GPS attitude sensors. After applying the impulse, the pilot took his hands off the controls and observed the aircraft response.

Parkinson believes GPS offers a relatively low-cost tool that can characterize an aircraft's performance in minutes. It may also be useful for providing high-quality dynamic response data to autopilots, producing more efficient corrections and a smoother flight for passengers. ■

NAVSYS DEVELOPS LOW-COST SENSOR

ALBUQUERQUE, N. M.



Collins Miniaturized Airborne GPS Receiver was the standard for airborne systems at the ION-92 conference.

Navsys Corp. has developed a GPS tracking sensor that can be manufactured for less than $100, according to president Alison K. Brown.

The sensor is specifically designed for applications such as radiosondes, sonobuoys and emergency location devices. The reason for the low cost is that the Navsys "Tidgit" sensor does not process the GPS signal on board the host vehicle. It samples the GPS signal and transmits a compressed sample back to a central facility over a conventional telemetry link.

In contrast, other GPS tracking systems use either a low-cost GPS receiver or a translator. The low-cost receiver solves the navigation problem and then transmits the position on a low bandwidth data link. Although the communication link is inexpensive, the GPS chip set to process the navigation data costs about $250 alone in large quantities, driving the receiver cost up to about $400.

Translator sensors currently are employed in missile tracking applications where small expendable sensors are required. The front end of a digital translator is identical to that of a GPS receiver, but the received signals are mixed to another frequency and retransmitted on a wideband data link.

THE SENSOR AVOIDS the expense of on-board digital signal processing and microprocessor chips, and the radio frequency subsystem eventually could cost as little as $100. However, the S-band power amplifier for the wideband data link currently costs over $1,000, Brown said.

Tidgit uses a radio frequency front end and frequency synthesizer similar to a GPS receiver. Instead of processing the GPS data, it takes digital samples and uses a patented compression logic to reduce the bandwidth of the signal it will rebroadcast to the central facility. Navsys developed a PC workstation for the ground central facility that can recover the measurements from all visible satellites and compute precise differential solutions in real-time.

A typical voice channel can accommodate a 65-kbps. data link, which is sufficient to relay Tidgit data back. The accuracy of the Tidgit solution depends on the bandwidth of the data link and the dynamics of the vehicle being measured. At 40 kbps., Tidgit horizontal accuracy would be 10 meters. At 15 kbps., that would drop to 100 meters, according to Navsys. ■

CNS Report

by Damon C. Hart

Conference Explores DGPS Applications

The Second Annual Conference on Differential Satellite Navigation Systems was held in Amsterdam at the end of March. A total of 392 delegates from 25 countries attended the four-day conference. Sixty-four technical papers were presented, and exhibitors from 27 companies displayed their wares and talked up their services.

Much of the technical program was taken up with descriptions of sub-meter, decimeter, and centimeter accuracies obtained using only the publicly available GPS C/A code.

Some attendees said privately that the conference spent too much time on accuracy and not enough on the other challenges that remain. "GNSS accuracy is no longer the issue," according to George Ligler, co-chair of the RTCA SC-159 working group on precision approach. "The real issues today are integrity and continuity of service and how to achieve these in a practical way." This is a good indication of how far this field has come very rapidly.

The "Stanford Bubble"

A paper by Clark Cohen of Stanford addressed the promising and exciting use of low-power pseudolites to permit precision final approaches with decimeter accuracies. Pseudolites are transmitters on the ground that emit GPS-like messages. If this approach proves to be practical, it could provide the accuracies required for Cat IIIB landings using GNSS.

Cohen's work is based on earlier GPS studies done at Stanford on aircraft attitude determination. Cohen described how one or more pseudolites could be used to resolve GPS carrier phase ambiguity during final approach. In this concept, the descending aircraft passes through the pseudolite-transmitted emissions, and uses these to correct its onboard GPS position solution to the required accuracy.

The very low power of the pseudolites (a few milliwatts) is a key part of the concept. This eliminates the vexing near-far problem of GPS satellite transmissions being overpowered by pseudolite transmissions when aircraft are in their vicinity. Low power also creates the characteristic form of the area in which the signal can be received—DSNS '93 attendees took to calling it the "Stanford Bubble."

Actual flight tests to validate the concept begin this summer. Cohen expects to have results to share with the community this fall at the GPS '93 Conference in Salt Lake City.

Progress on Multipath

In differential GPS applications, the main sources of error are noise and multipath. Many current receivers provide effective filtering techniques that reduce the noise problem. Multipath remains a serious impediment, particularly in precision navigation applications on or near the ground.

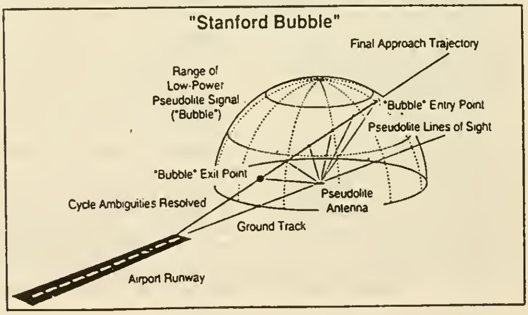
In his paper, "Optimum DGPS Receiver Structures," Richard D.J. van Nee of the Delft University of Technology in the Netherlands proposed a technical method that would reduce the multipath problem to manageable proportions within GPS receivers. This new receiver structure is called MEDLL (Multipath Estimating Delay Lock Loop). A prototype MEDLL receiver is under development at Delft.

Identified by some attendees as the "biggest breakthrough of the conference," van Nee's report was named best paper by the conference organizers.

If successful in practice, this technique could have significant implications for airport surface surveillance and precision approach. It may reduce receiver multipath problems to a level where high-integrity movements on and near the airport surface would become routinely possible.

Airport Surface Surveillance/Control

More than just theory was presented at the conference. Klaus Mohlenkamp of the Institute of Flight Guidance and Control of the Technical University of Braunschweig, Germany, presented the results of a prototype taxi guidance system called GINaS (Ground Information and Naviga-


"Stanford Bubble"
Final Approach Trajectory
Range of Low-Power Pseudolite Signal ("Bubble")
"Bubble" Entry Point
Pseudolite Lines of Sight
"Bubble" Exit Point
Pseudolite Antenna
Cycle Ambiguities Resolved
Ground Track
Airport Runway

tion System).

GINaS has been built into a modified Volkswagen van, whose controls (steering, accelerator, brake) have been modified to permit direct computer control. GINaS consists of a DGPS receiver in the van, a 486 notebook computer with specially developed software, and a digital map of the Braunschweig airport. GINaS has successfully controlled and maneuvered the van around the surfaces of the airport, shown in operation on a video. Furthermore, the van itself was available in the parking lot of the conference for examination by attendees.

GINaS allows the institute to conduct studies in the use of DGPS for surface navigation of aircraft and airport ground vehicles. Three different levels of system integration are being explored:

- assistance to the pilot or driver
- supervision of the pilot/driver
- automatic control of the aircraft/vehicle

One of the major challenges being explored is the display of position information to the pilot/driver. Currently, a standard EFIS display is used in the test vehicle. One of the goals of the tests is to use existing cockpit equipment for ground location display. This will lower the cost and accelerate the acceptance of GINaS by the airlines.

Multipath and the imprecision of existing airport digital maps remain problems. Braunschweig is looking for vehicle control accuracies down to one meter. Most of the maps they have examined do not come close to providing this. If the map is not at least as accurate as the control system, the aircraft will not stay on the taxiway/runway.

Integrated GPS/GLONASS

Wolfgang Lechner of the Avionics Center of Braunschweig described his group's work on integrating differential GPS and GLONASS into a single navigation unit.

His experiments included the use of the GLONASS ATN-16 (one channel, slow sequencing, L1/CA Code) and several GPS receivers, notably the Trimble 4000 SST (eight channel, L1/L2/P Code). The same antenna was used for both receivers. The raw satellite data from the two receivers were processed by a computer which "harmonized time and geodesic differences between GPS and GLONASS to

(Continued on next page)

Quality Instrumentation

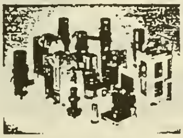
- Instruments for fixed and rotary-wing aircraft
- Engine instruments and Flight instruments
- Over 10,000 items available for sale or exchange
- Computerized control of inventory
- Excellent pricing and fast delivery

A | S
AVIATION
INSTRUMENT
SERVICES, INC.

12213 S.W. 131st Avenue
Miami, Florida 33186
Telephone: (305) 251-7200
Fax: (305) 251-2300
Telex: 52-5110 APS MIA

Circle Reader Service No. 74

PRESSURE MEASUREMENT
With Accuracy and Stability



Accuracy	0.01% FS
Stability	0.01% FS per year
Repeatability	0.001% FS
Rugged and Reliable	
Inherent Digital Output	

The Schlumberger Vibrating Cylinder Pressure Transducer is specified throughout the Aerospace Industry, where Accuracy, together with long term stability, is of high importance.

For airborne and ground-based equipment, where accuracy and reliability is required, there is only one choice. This Vibrating Cylinder Transducer is used in FADEC systems, ADC systems, Solid State Altimeters, and in the majority of ramp Air Data Test Sets.

To find out more about The Schlumberger Vibrating Cylinder Transducer, just contact us, at the following address.

USA: 217 Technology Drive, Suite 100
Irvine, CA 92718
Tel: (714) 753-1773 Fax: (714) 753-1672

UK: Victoria Road, Farnborough
Hants, GU14 7PW
Tel: (0252) 544433 FAX: (0252) 371216

Schlumberger Industries
Aerospace Transducer Division

Circle Reader Service No. 75

(Continued from previous page)

produce a combined navigation solution," according to Lechner.

Others (notably 3S) are already offering receivers that can provide either a GPS or a GLONASS solution. This is the first time, according to Lechner, that anyone has been able to use the signals from both constellations in the same solution.

The importance of these results is the overall improvement in availability for navigation systems integrating both systems. When both constellations are complete, there will always be a sufficient number of satellites over the United States (for example) to provide precision navigation without interruption.

GNSS/Inertial Solutions

A number of papers were presented that explored the architecture of integrated navigation systems, with GNSS as one sensor component. The most common non-GNSS components discussed at the conference were inertial sensors. This supports the position that the sort of integration currently under test by Honeywell, Boeing, and the FAA offers the highest probability of eventual success.

The complementary nature of GNSS and inertial sensors were repeatedly highlighted by the speakers.

- Inertial sensors are self-contained and continue to operate even when there are problems with satellite signals.
- GNSS requires no initialization, and can even be used to initialize inertial sensors, which do require such initialization.
- GNSS can be used to measure position and speed; inertial measures acceleration, turn rate, and attitude.
- Inertial sensors tend to drift; GNSS does not drift.
- GNSS on its own has relatively low integrity; inertial sensors on their own have very high integrity.

Gunter Hein of University FAF Munich proposed an architecture for a high-precision aircraft navigation system based on GPS and INS. The basic components of the system are "differential GPS using carrier phase ambiguity resolution on-the-fly, telemetry using new carrier phase corrections, coning and sculling compensation in the strapdown algorithm, and INS in-flight alignment capability." He concludes, "High-precision aircraft navigation using DGPS/INS integration of the latest state of the art is able to deliver 5 cm in position and about 2/10 of a minute of arc in attitude."

Aerodata has already announced a commercially available product called AeroNav that integrates GPS, GLONASS, and inertial sensors. Aerodata claims "decimeter accuracies achievable in real time" with this product. "A close coupling of GNSS with complementary inertial sensors improves [navigation] system performance under all phases of flight," according to Aerodata. Such a system "has much better integrity than a stand-alone satellite navigation system."

Bernd Tiemeyer of the Technical University Braunschweig reported that using "low-quality (low-cost) gyros and accelerometers in combination with normal satellite navigation receivers for high-accuracy applications" showed significant promise. Kalman filtering techniques are an essential part of the integrated unit. He predicted "such an integrated navigation system will be able to replace ILS."

Proposed GLONASS Extensions

Integrated navigation solutions with both

ANTENNAS ARE OUR BUSINESS...

To support you, and your customers, we provide antennas of the highest quality and reliability for the ultimate system's performance. You can rely on our 45 years of experience supplying antennas for the following systems

- COMMUNICATION
- VOR/ILS
- MARKER BEACON
- GLIDE SLOPE
- DME/TRANSPONDER
- RADIO ALTIMETER
- RADIO TELEPHONE
- GPS
- SATCOM
- T-CAS
- MULTI-SYSTEM COUPLERS
- ELTS

IF YOU USE ANTENNAS, SELECT DORNE & MARGOLIN!

— Call Or Write Today For Additional Information, Or Contact One Of Our Authorized Distributors —

- RYDER AIRLINE
- RYDER AVIALL
- EDMO
- COOPER AVIATION
- DALLAS AVIONICS
- AVIONICS INTERNATIONAL
- AVSCO
- BRITTANIC AVIATION LTD. *(Europe)*

DORNE &
MARGOLIN, INC.
A United Capital Company

2950 Veterans Memorial Highway, Bohemia, NY 11716
TEL (516) 585-4000 • FAX (516) 585 4610

Circle Reader Service No. 76

GPS and GLONASS present a technically complex task. Many of the issues surrounding these are under investigation by researchers in the community.

Differential techniques will certainly play a role in integrated solutions. At present, the community has a standard format, RTCM-104, used to transmit differential GPS corrections to GPS receivers. Most of the differential GPS receivers on the market today are compatible with this standard

Valentin Shebshayevich of the Russian Institute for Radionavigation and Time (RIRT), introduced as "the father of GLONASS," proposed to the conference that RTCM-104 be extended to accommodate the additional fields needed to carry GLONASS differential corrections. His idea is to "amplify the RTCM recommended draft standard (without changing anything in it) so that the new combined standard would cover both the possibilities of joint use of GLONASS and Navstar (GPS), and the independent utilization" of either system.

This would simplify integrated solutions, but would add to the size of the correction messages. Some of the attendees feel that GLONASS needs to prove itself as a viable constellation before the community adds this transmission overhead.

Extended Life for ILS?

There is a growing level of confidence in the aviation community that GNSS will, in the not-too-distant future, be ready to support precision approaches down to Cat IIIB. A key question is when Can the technology and all associated operational procedures be ready in time to replace the existing ILS systems, which must be phased out by 1998? Even some of the strongest proponents of GNSS in aviation have doubts.

The question is important. 1998 is the date by which all ICAO states must, under current agreements, equip their international airports with the proven, but more expensive, MLS landing systems. Most countries would prefer to avoid this massive investment, if GNSS can offer equivalent functionality in the near future.

1995 is the decision date for launching the MLS installation program in most countries. FAA has recently undertaken a study to help it determine the near-term feasibility of GNSS to support Cat II and Cat III landing systems. The results of this study are due in 1995.

Some of the attendees said that they would like to consider extending the protection of current ILS frequencies for a few more years. This would give GNSS time to be proven and fielded. It would, of course, also mean renegotiating the ICAO agreements on MLS, a non-trivial undertaking. But potential savings are high.

INTRODUCING: OVERNIGHT DELIVERY OF EFIS SWITCHES AND INDICATORS

STACOSWITCH'S LIGHTED PUSHBUTTON SWITCHES ARE NOW IN STOCK AT DALLAS AVIONICS

Custom Tailored for today's aircraft, StacoSwitch's AV17 Series gives you:

SERVICE StacoSwitch has teamed with Dallas Avionics, your preferred avionics distributor, to handle all your lighted pushbutton switch and indicator needs.

SELECTION 230 standard EFIS legends, six lighting colors, four light circuits and two switch circuits, add up to one very versatile switch product.

STYLE Our Sunlight Readable "deadfront" legends provide a sleek, modern look.

With its rugged Mil-Spec design performance, you get a lifetime tactile feel that instills confidence. You can depend on it.

NO RUSH CHARGES, JUST RUSH SERVICE

CALL DALLAS AVIONICS today for your avionics switch design catalog and lighted pushbutton legend library.

800 527-2581 Dallas
800 241-3739 Atlanta
800 523-0841 California
800 523-5949 Philadelphia

STACO SWITCH
Aero Products Group
COSTA MESA, CA

Circle Reader Service No. 77

TESTIMONY OF

WILL FAVILLE, DIRECTOR

SAFETY AND TECHNOLOGY

BEFORE

THE AVIATION SUBCOMMITTEE OF THE

HOUSE PUBLIC WORKS AND TRANSPORTATION COMMITTEE

SATELLITE TECHNOLOGY

JULY 28, 1993

NATIONAL AIR TRAFFIC CONTROLLERS ASSOCIATION MEBA/AFL-CIO
Suite 701 • 1150 17th Street, N.W., Washington, D.C. 20036 • 202/223-2900 • Fax 202/659-3991

Good morning Mr. Chairman and members of the Subcommittee. My name is Will Faville and I am the Director of Safety and Technology for the National Air Traffic Controllers Association. NATCA is the exclusive representative of this nation's 14,700 air traffic controllers employed by the Federal Aviation Administration (FAA).

I want to thank you, Chairman Oberstar for having this hearing today. The Global Positioning System (GPS) is a technology that will change the face of aviation in the United States and throughout the world. Its applications are limitless. We could have radar-like presentations for all parts of the world. Cost would be much less than some current technologies under consideration at the FAA.

Last month, we appeared before this body to recommend ways the FAA "could do more with less." One of our recommendations was to fully accept the new technology of GPS and to stop throwing good money at Precision Runway Monitoring (PRM), Microwave Landing System (MLS) and Oceanic Display And Planning System (ODAPS). We believe that GPS could replace all of the named systems with a more precise and cost efficient system.

PRM is a system that will be obsolete before it becomes fully operational. The first operational model just went into Raleigh-Durham (RDU). Unfortunately, the FAA is considering a replacement model next year.

As we mentioned last month, the initial desire for MLS in the late sixties and early seventies was well founded. However, since that time, many of the deficiencies of the Instrument Landing System (ILS) have been resolved. The MLS remains a very costly replacement. The cost is not only experienced by the FAA, but it is felt by the airlines as they retrofit their aircraft for MLS ability. Utilizing GPS technology will provide the user with a more cost-effective, true precision approach.

Mr. Chairman, you are well aware of the delay and rising costs involved with the FAA's attempt to bring a fully-functioning and reliable ODAPS to life. What started out as a 36 month/$22M project has escalated into a 100+month/$51M project, and the end still is nowhere in sight.

These are but a few of the projects that should be terminated. The monies appropriated by Congress and the personnel delegated by the FAA to these projects should now be invested into GPS, before we lose our competitive edge.

I know that the FAA testified earlier that it is fully committed to GPS. Unfortunately, it's actions are not keeping pace with it's words. The FAA's GPS office is currently staffed by two people full-time. Two other temporary details are allotted; but, they are tasked with the responsibility of developing the FAA's internal training system for GPS. Recently, an additional two full-time positions have been authorized; but, they have yet to be filled. The FAA Regions are in worse shape. Each region has an individual assigned to GPS; but, this is as an "additional duty." The FAA must fully staff these available positions and seek to increase it's staffing in the GPS area. Without the proper support, the FAA's effort will be a band aid approach, with pilots and controllers being left out of the loop.

Air traffic controllers across the nation do not know anything of the FAA's plans in regards to GPS. Apparently, the GPS office in Washington developed a controller briefing package and sent it to the field months ago -- to date, very few controllers have been briefed. Those few controllers who knew of GPS, happened to be private pilots and gathered information from other non-FAA organizations.

The FAA plans to test several applications for GPS at various airports throughout the U.S. by the fall of this year. Testing is to be conducted at the Oshkosh Air Show, Dallas-Fort Worth, and, Juneau. Air traffic controllers at those facilities have, again, been frozen out of the loop. This cannot be allowed to continue.

GPS can be a very valuable technology for the FAA and our nation's troubled airlines and aviation system; but, meaningful controller involvement is a must.

All too often, controller involvement is grudgingly permitted by the FAA. We witnessed this with TCAS and AAS to name a few occasions. The FAA must understand that the air traffic controllers and their input into new technology are a very valuable resource available to them. NATCA firmly believes that a

NATCA liaison office should be associated with the GPS office at FAA Headquarters. This is very similar to our current relationship with the FAA on AAS.

Thank you, Mr. Chairman. I will answer any questions that you or members of the panel may have.

STATEMENT OF
ROBERT R. FERGUSON, III
PRESIDENT AND CHIEF EXECUTIVE OFFICER
CONTINENTAL AIRLINES, INC.
BEFORE THE
AVIATION SUBCOMMITTEE OF THE
HOUSE PUBLIC WORKS AND TRANSPORTATION COMMITTEE
FUTURE USES OF SATELLITE TECHNOLOGY IN AVIATION
JULY 28, 1993

Good Morning Mr. Chairman. My name is Robert R. Ferguson, III and I am the President and Chief Executive Officer of Continental Airlines. I am pleased to be able to testify before this subcommittee on an issue of great interest to the aviation community at large and to me personally.

Before I move on to the more technical aspects of my testimony, I would like to publicly commend the National Commission to Ensure a Strong Competitive Airline Industry and specifically Commissioner Barclay whose System Capacity Team thoroughly addressed the Global Positioning System (GPS) issue. The first working draft of the Commission, dated July 19, makes two dramatic and worthwhile recommendations under the section titled "Air Traffic Control for the Future". The first recommendation is to "change the U.S. air traffic control system to a satellite - based navigation system, integrated with a modernized Air Traffic Control (ATC) system". The second recommendation is that the "FAA and industry should pursue efforts to accelerate the implementation of the GPS and air traffic control modernization through such means as a public - private consortium, designed to develop and implement improved technology expeditiously". Mr Barclay and his fellow Commissioners have well grasped the significance of this technology and I appreciate their attention to this important issue.

Since the beginning of recorded history, mankind has sought to be able to determine where he is in relation to any other person or thing. Today it is possible to determine instantaneously, continually and exactly where anyone or anything is, anywhere in the world or its surrounding atmosphere, repeatedly and reliably. The technology to allow this to happen is based on the satellite constellations orbiting the earth today.

These satellites provide a number of unique opportunities to aviation. We are on the threshold of redefining the entire manner in which we conduct aviation worldwide. Through the use of a satellite system, and various communication systems, it is now possible to safely navigate anywhere on or around the earth with absolute certainty as to speed, direction, altitude, time and collision avoidance. There are three basic elements of aviation that are impacted by the technological enhancements brought forth through satellites:

Communication The ability to communicate through voice

	and data transmissions virtually worldwide.
Navigation	The ability to navigate accurately and reliably anywhere in the world without adding one more ground based navigation aid such as a VOR or Non Directional Beacon (NDB).
Surveillance	The ability to precisely track aircraft and other aviation related vehicles anywhere in the world.

Communication

Today we communicate with our aircraft through a series of VHF of HF voice transmissions. In some cases these transmissions must be relayed through stations other than the intended receiver due to range limitations of the equipment. Passengers are likewise limited to communication within short ranges and are often out of touch with home offices for hours during long transoceanic flights.

The most compelling reason to improve the method of communication is safety. According to the FAA, twenty five per cent of the domestic operational errors have been attributed to miscommunications. Digital communications, (i.e data streams that result in printed or displayed commands), will reduce, if not eliminate, these errors. Communications which use these electronic messages are also faster and therefore more efficient in the use of the limited radio frequencies. The future will bring data transmissions via satellites or HF that will bring the user in direct contact with the provider.

A second reason to improve the method of communication is that the existing communication system has resulted in delays that one carrier has estimated for itself to be more than $300 million annually. These unacceptable costs resulted from 8.5 million minutes of delay either during flight or while taxiing.

A creative approach to improving the communications system is presently occurring wherein the airlines, the FAA, and the private sector are forming a consortium specifically tasked with the development of a communication's "router". This "router" will format a message, determine the media to be used (HF, VHF SATCOM) and the priority of the message to get transmitted. By using the consortium approach the normal processes involved in producing an airline avionics product could be eliminated. This arrangement is felt to be so effective that it is anticipated it will reduce the development and acquisition process by as much as two years. If this proves to be correct, the result will be $600 million in savings for the one carrier referenced in the previous paragraph.

This type of innovative approach must be repeated in other phases of the transition to the Future Air Navigation System.

Navigation

In recent weeks, I have participated on two panels before the National Commission to Ensure a Strong Competitive Airline Industry and on each occasion I have emphasized Continental's strong views on the benefit of satellite navigation. As I said to the Commission, immediate benefits from sole source navigation using satellites can be achieved today resulting in savings for the U.S. airlines in the range of 1.5%, which equates to $525 million annually, for the domestic enroute sector alone.

For example, $283,000 per month per aircraft could be saved on any carrier's North Pacific routings given the flexibility afforded through the use of satellite based technology. In the Atlantic, reducing the spacing on oceanic flights, vertically from 2000 feet to 1000 feet, laterally to 30 NM from 60 NM and in trail from 20 minutes to 10 minutes, could increase the traffic by 4 times the present capacity. This would result in a greater ability to operate our aircraft at optimum altitudes and routes.

Clearly, arrivals and departures will benefit from a more accurate system. For example, separation for approaches to parallel runways will be safely reduced to 3200 feet from the present 4300 feet. According to the FAA, the 4300 foot separation standard in effect today which requires a special radar and additional controller would no longer be necessary. The impact is greater airport capacity with satellite based navigation at less cost.

Departures will benefit from reduced obstacle separation requirements. Today, protected areas surrounding obstacles that penetrate the projected departure path require aircraft to either climb quicker or maneuver to avoid these areas. Payload restrictions to allow the aircraft to climb quicker are often the result. These protected areas are designed based on the limitations on the accuracy of the present navigation systems. With the increased accuracies afforded by satellite navigation, the protected areas may be shrunk, thereby safely allowing the carriers increased payloads.

Because these systems are so economical, it will be within the financial reach of nearly 4400 domestic airports to implement precision approaches in adverse weather and visibility conditions.

The satellite systems are easier to use, more accurate and less costly to maintain than our present ground-based system. The total savings estimated as a result of using satellite navigation is $2.6 billion - $6.7 billion in one time costs and $524 million annually, excluding ATC. Every day that we do not have the full benefit of satellite navigation costs the government, the industry and the passenger millions of dollars because they are forced to pay for an antiquated and costly ground based system.

Mr. Chairman, I am pleased to report to this subcommittee that Continental is in the process of equipping some of our Continental Express commuter fleet with GPS navigation for use in enroute and terminal procedures. This fall, we will become the first airline using GPS based approaches. We are also evaluating a number of manufacturers to determine which will become our supplier for the future GPS products. That selection is close to completion and installation will likely commence before the end of this year.

Surveillance

With the rapid advances described above, we will soon be able to communicate position reports automatically via satellites or HF datalinks that will pinpoint an aircraft's position within 100 meters. These position reports would allow the replacement of expensive ground radar units that are presently providing only limited areas of coverage. The automatic reports would allow the detection of gross navigation errors in the oceanic areas resulting in the reduced vertical and horizontal separations described earlier to be achieved.

Airport surface surveillance can also be based on satellites. Very precise signals achieved through a combination of satellite and ground based units can achieve accuracies of 1-2 meters. With this level of accuracy, electronic maps can be developed for navigation on the airport surface. This very basic step, already in place in some motor vehicles today, can improve ground handling during poor visibility conditions and improve safety by reducing the possibilities of runway incursions. Combined with a modern communication system using data transmissions, a system to control surface movement and guidance would be more efficient and effective than the elaborate lighting and signage being implemented today.

Progress

Each of the above areas has a clear advantage in real dollars. These are savings that will ultimately be passed on to the traveling public and the taxpayer. The technology which permits all this is inexpensive and readily available. However, it must be understood that to achieve the maximum benefit from the individual elements, the complete system must be in place. For instance, enroute satellite navigation will produce some cost savings, but the full benefit cannot be realized until the Air Traffic Management system can achieve the communication and surveillance elements necessary to extend the benefits to approaches and departures. Without all of these elements in place, the benefits of the system are reduced substantially.

On the airline side of the equation, the capital outlay to equip the aircraft is substantial; avionics related products (for the entire industry) in the GPS market are expected to be between $500 and $740 million. As an industry, we can benefit from the transition to satellite based aviation but we must still be able to afford the cost.

The Automated Traffic Management system required to utilize the information lags well behind the timeline for the remainder of the elements. It will do no good to equip aircraft with expensive avionics that can do nothing more than be used to operate the aircraft in the same manner as we do now. Automatic processing of the data to and from the aircraft and automatic routing of aircraft on optimum flight paths must become the norm. With this ability we will be able to free the air traffic controller from normal aircraft routing to manage the abnormal and emergency situations, thus providing a safer environment to operate. And the carriers will operate closer to the optimum capabilities of the aircraft, thus achieving the reduced direct operating costs.

Implementation

Every day that goes by, every minute that is lost due to indecision or lack of direction is costing this industry in terms of safety and operating expenses. Hundreds of millions of dollars, if not billions are being lost annually. Instrument approaches to almost 4400 additional airports will cost little to achieve because there is no additional, expensive, manpower intensive system that is required to accomplish this.

It is not important whether or not we utilize the NAVSTAR GPS, or GLONASS, or IMMARSAT as the provider of the satellite signal. Much debate has occurred developing these alternatives and attempting to provide a global solution that is acceptable. It would seem that with 45% of the aviation traffic in the world, the United States should focus on the continental US, implement a system using the GPS which are already in place, and gradually expand that to the western hemisphere and Europe.

The expected benefits of a fully implemented system will justify the investment; however there is a need to provide airlines with early benefits to offset costs. An optimistic scenario for global implementation is that it will take about 14 years from the time the need is identified to the time the system has full operational use. In this time, interest alone will amount to $3 for every $1 invested. Therefore, if early benefits are not achieved, the accumulated interest may outgrow the predicted operational benefits.

There is also a need to question traditional assumptions and procedures within the FAA in an effort to shorten the implementation timeline. It is clearly unacceptable to delay implementation of this new era because of parochialism. A top down audit should be accomplished of FAA personnel, budget and assignments to eliminate overlapping of conflicting areas of responsibilities regarding satellite based aviation and the FAA's focus should be maintained on ensuring earliest possible benefits.

Mr. Chairman, before I conclude my statement, I would like to offer five recommendations for the Subcommittee to consider:

Recommendations

- Establish a centralized authority within the FAA to oversee the earliest benefits possible for the investor airlines.
- Support a progressive approach to acquisition, such as use of a consortium.
- Establish a GPS based precision approach criteria and implementation plan that will eliminate any requirements to equip aircraft with MLS systems.
- Accelerate the selection of vendors, including sole sourcing, if it will accelerate implementation.

- Mandate implementation of the program domestically while moving negotiation with other countries to a "fast track."

Again, Mr. Chairman I appreciate the opportunity to appear before the Subcommittee and I will be happy to answer any questions you may have at this time.

Statement of the Air Transport Association of America, Before the
House Committee on Public Works and Transportation
Subcommittee on Aviation, on
Future Uses of Satellite Technology in Aviation
July 28, 1993

Mr. Chairman, my name is J. Roger Fleming. I am Senior Vice President, Operations and Services, Air Transport Association of America (ATA). ATA represents 17 U.S. air carriers. I am pleased to have this opportunity to present the views of these carriers on the safety and other operational advantages of implementing satellite based navigation and communications technology in domestic and oceanic airspace and the need for assistance from this Committee and FAA to help airline and other civil aviation users in their efforts to benefit quickly from these technologies.

The International Civil Aviation Organization (ICAO) initiated discussions in the mid 1980s regarding an eventual transition to space-based communications, navigation and surveillance services. A broad conceptual framework for this transition was developed and the concept is known as "Future Air Navigation Systems" (FANS). The navigation component of FANS is identified as Global Navigation Satellite System (GNSS) and the U. S. Department of Defense Global Positioning System (GPS) is a key element of GNSS. It is hoped that the Russian GLONASS system will eventually become another important GNSS component since GLONASS will greatly enhance the operational utility of GPS. The other elements of FANS are satellite based communications capability, a surveillance technique known as "Automatic Dependent Surveillance" and a more flexible and efficient ATC system operational mode described as "Air Traffic Management."

The prospective benefits of FANS for airline users are: improved safety, because of the inherent capability of the GNSS to enable precise navigation in three dimensions as well as in an accurate, common time reference; improved operational efficiency resulting from the ability to fly any desired route in terminal or enroute airspace as well as enabling ATC to reduce separation between airplanes flying in airspace with no ATC radar surveillance (e.g., over ocean); reduced cost of acquisition and maintenance of airborne navigation systems that will become redundant (e.g., VOR, DME, NDB, some inertial systems, MLS and possibly ILS). Also, the airborne collision avoidance system known as TCAS II will probably migrate to GNSS for position and time reference to improve functionality.

The GPS satellites are in orbit. DoD is expected to declare the GPS constellation fully operational not later than early 1994. However, GPS was not designed for civil aviation use and will require augmentation, especially for the most demanding civil aviation application: precision approach. GLONASS is one prospective enhancement that would increase availability, or the number of satellites in view of the user. Other augmentations, such as differential stations, may be required to ensure needed system accuracy and integrity. Final decisions have not yet been made concerning the exact requirements for civil aviation use. All the ongoing technical trials involving GPS/GNSS are intended to answer questions concerning augmentations required for the satellite systems as well as modifications needed for the airplanes and FAA certification standards applicable to both.

ATA member airline interest in GPS/GNSS applications is strong and is reflected in the work program of the association. The highest priority airline objectives are those which will produce early operational benefits: use of GPS/GNSS to fly diverse routings in terminal airspace, to achieve precision approach capability and to permit reduction of separation and timely attainment of optimal routing and cruise altitude on critical over ocean segments (e.g., Los Angeles to Sydney). Cooperative FAA/airline programs to achieve these objectives include several phases. For example, the precision approach project starts with more flexible routings in terminal areas, progresses to non precision approach and moves on to precision approach. The over ocean project starts with inertially derived aircraft position relayed to the oceanic ATC center by satellite communications link and transitions later to GPS/GNSS position data linked to ATC.

Ultimately, the objective of FAA and all the users is to transition to the FANS air traffic management concept which will, when implemented, allow operators to fly conflict-free user preferred routings from departure point to destination. This objective will require highly accurate navigation capability on the airplane, near instantaneous communications capability between the airplane and the ATC agency and a high degree of automation in the ATC system.

The transition to FANS will be costly and must be planned carefully to ensure that the introduction of benefits justifies the investments that will be required by both governments and users. Focus on early operational benefits can, we believe, drive the implementation process, both within U. S. airspace as well as in international airspace.

FAA and airlines, working together, are pursuing early operational benefits that can be realized by utilizing GPS/GNSS and advanced communications capability. You have already heard from Mr. Robert Ferguson about the operational benefits that are being sought by Continental Airlines. Other ATA member airlines are working with FAA and manufacturers on complementary development programs. For example, United and Northwest are pursuing over-ocean benefits associated with the introduction of Automatic Dependent Surveillance (ADS) techniques on the Los Angeles-Sydney route. American is working actively on achieving Category I landing minimums using an integrated GPS/inertial navigation solution on a B 757 aircraft. This effort will be extended later, in cooperation with Boeing and others, to seek FAA certification of autoland capability and, ultimately, Category III landing minimums. A number of airlines are pursuing FAA approvals to operate on discrete terminal area arrival and departure paths that do not depend upon flight over a specific ground based navigation aid. At the present time these discrete routes are based upon DME (distance measuring equipment) updating of inertial navigation systems. In due course, the updating will be accomplished using GPS to further improve navigation accuracy and the utility of the aircraft's Flight Management System.

All the activities I have just described are being pursued based upon the promise of safety and operational benefits that can, in the airlines' judgement, justify the cost of the necessary modifications to the airplanes. However, the potential benefits are all dependent upon FAA actions, as well as industry actions. The ability of FAA to deliver what is needed in a timely manner will be critical to the pace of implementation of new technology in the National Airspace System, as well as in the oceanic areas where FAA provides air traffic control services. The airlines, as well as other civil aviation users, are able to implement the new capabilities far more rapidly than FAA is able to effect the necessary ATC system and institutional changes, but the pace of airline equipment modification will be tempered by the requirement to achieve a rapid payback on the capital that must be invested in the new technology. The evolution to space-based systems will be governed primarily by economic and institutional considerations, not by technology. The technology is available; the issue facing us now is whether the Administration, the Congress and the industry, working together, can develop and execute a plan that will result in implementation of the promising new capabilities in a reasonable time frame. We seek your support for such an effort, Mr. Chairman.

FAA requested the Radio Technical Commission on Aeronautics (RTCA) to assist in laying out a road map for the agency and industry to follow in securing early operational benefits from GPS and the coming evolution to digital communications capability. Mr. Watrous has informed you of the work accomplished by RTCA Task Force 1 and the ongoing work in Task Force 2. FAA has initiated a number of efforts to achieve early benefits from introduction of GNSS capability. The FAA Research, Engineering and Development Service has published an "FAA Satellite Navigation Program Master Plan," to provide "requisite research, development, planning, programming and implementation guidance for the FAA's implementation of satellite technology in the areas of navigation and communication." (Program Description, page E-3.) The Flight Standards Service sponsors an active Satellite Operational Implementation Team "to establish the technical, operational, and certification requirements and procedures for using satellites for navigation and communication." The Air Traffic Service is drafting an Implementation Plan for Satellite-Based Technology.

FAA cannot be faulted for lack of effort. But the agency is large, geographically dispersed and management is diffused. There is no central authority to ensure that all the necessary pieces come together at the right time and in the right manner to achieve the operational benefits sought by the users. Further, experience indicates that the agency will suffer procurement difficulties with some elements of the plan with resultant program delays. It is also likely that some important criteria or procedural element will not be completed in time or that some certification issue will arise late in the program and force rework of hardware or software. A systems management approach is required to ensure that these kinds of problems are identified early and dealt with before the satellite implementation program is seriously delayed.

Airlines have been critical of the FAA timetable and milestones laid out in the

Satellite Navigation Master Plan. We are all going to have to exercise imagination and leadership if we hope to realize the potential advantages of satellite technology in a reasonable time frame. We hope you will be able to assist us in achieving these goals, Mr. Chairman, by urging FAA to: (1) develop a single, integrated plan to implement the new technologies for the purpose of realizing the safety and operational benefits for both the government, the U. S. manufacturing industries and the users; (2) develop and put in place a management structure and process to ensure that the diverse elements of FAA are pulling together in a coordinated manner and time frame; and (3) identify any additional resources that may be required to execute the program.

Thank you, Mr. Chairman. I am prepared to answer any questions you may have.

MOVING INTO THE NEW AIRSPACE
HOW CAN THE JOB BE DONE?

By

Captain David R. Haapala
Northwest Airlines

In 1961 President Kennedy announced to the nation that the United States should "before the end of the decade" put a man on the moon. In the summer of 1969, eight years later, astronaut Neil Armstrong radioed these famous words to an anxious population on Earth: "Houston, Tranquility Base here. The Eagle has landed."

In 1983, the International Civil Aviation Organization (ICAO) began work on its definition of the future air navigation system (FANS). In 1987, it published that plan in its FANS Report. Now, in 1993, ten years after it commenced its formal work and six years after publishing its plan, the aviation community is wondering when that future implementation will finally happen.

The operational and economic implications of FANS are enormous. The FANS Report claims that the world's airlines can save $5 billion a year in reduced fuel usage and time savings based on improved routing, closer to optimum altitude selection, fewer disruptions and better communications for operational control. Beyond that airlines can potentially reduce avionics-equipment cost by removing old single-function navigation systems like ILS and replacing them with universal (takeoff to landing) systems based on the U.S. Air Force's Global Positioning System (GPS) or Russia's comparable system called GLONASS.

Savings on ground-based navigation infrastructure is possible too. According to statistics released by ICAO, reduced demand for ground-based equipment and associated maintenance costs could save $450 million per year.

These very significant savings come with a much more capable system as well. Northwest and other carriers, which have studied and tested these space-based navigation and communications systems, believe that they can effectively replace ILS and its substitute MLS (not without controversy, however, especially in Europe); all of the present VHF navigation system; all marker beacons; all compass locators; all distance measuring equipment (DME) signals and the high frequency (HF) radio communications system which pilots have complained about for decades. Further, while replacing these old, less reliable and expensive units, airlines and other aviation users will be able to fly to more runways at more airports in more adverse conditions with greater precision and safety.

Northwest is also very actively pursuing the promise of enhanced vision which will complement space-based navigation systems during takeoff, landing and taxi operations as well. Northwest is excited and encouraged about enhanced vision because it believes that EVS can allow operations during times of reduced visibility - including darkness - to any runway without expensive upgrades to lighting and ground control systems which are required with other alternatives.

It is not hyperbole to state that the entire aviation industry is on the threshold of momentous change in the way of doing business because of new satellite and terrestrial data communications, satellite navigation and improved situational awareness with new enhanced vision systems.

In the fall of 1992, a task force of U.S. experts, organized by RTCA (a FAA advisory organization), published recommendations on the early implementation of what it described as the Global Navigation Satellite System (GNSS). Now in 1993, a similar second task force is working on a corollary project for data communications which will be the other vital enabling piece of the envisioned new airspace system.

How can we speed the migration to tomorrow's more capable air traffic management (ATM) based on satellites and data communications? What sort of organization should be proposed to do this? How should it be funded? How can it be realistic, workable and practical rather than theoretical, bureaucratic and ponderous?

WHAT IS THE PROBLEM?

The development and implementation of the new ATM system is nearly stalled. Simple changes such as pre-departure clearances and automatic terminal information services have taken years to introduce and are available at only a few locations. Oceanic clearances across the North Atlantic are still overly ponderous and not universally available. More ambitious programs, such as the microwave landing system (MLS) and the advanced automation system (AAS) have been years behind schedule. Route economies and improved safety based on automatic dependent surveillance (ADS) are seen as being at least five years away.

The problem is not the people, it is the system. The aviation community - including the FAA - has many intelligent, talented and energetic people. There are also many well managed, committed organizations which are dedicated to aviation's continued success. Yet, many feel frustration that progress toward the promised rewards of the new satellite-based communication, navigation and surveillance (CNS) system is near paralysis.

Complicating this situation is the extremely poor economic situation in which most of the world's airlines find themselves in 1993. Because of heavy operating losses for several years, many airlines simply do not have the resources necessary at this time to make investments of several millions of dollars no matter how desirable the operating benefit.

Northwest Airlines desires to achieve new operating efficiency in oceanic regions and terminal areas using these technologies. However, the investment analysis necessary to justify appropriate equipage becomes problematic because the benefits cannot be fully realized until a complementary ground infrastructure is developed and fielded which will support ADS and other navigation improvements.

NEW THINKING IS CALLED FOR

A number of concerned people have begun to have doubts about the development processes which the industry has traditionally used in the past. Some are openly doubting the capability of customary institutions and their bureaucracies to adequately deal with this formidable task.

Here are some reasons why the process is so slow:

THERE'S TOO MUCH DIVISION

The aviation industry has evolved over nearly a century. Because of its geographical scope and considerable complexity, a number of disciplines and organizations have been created to manage it. These independent institutions include governmental bodies such as ICAO and the world's CAAs. It also includes consensus and standardization bodies such as the AEEC and RTCA. Market-driven organizations include airframe manufacturers, avionics vendors, airlines and, to some degree, service providers, such as ARINC, SITA and INMARSAT. Advocacy or advisory groups include AOPA, NBAA, ATA and IATA and "think tanks" such as NASA, Mitre and Lincoln Laboratory.

Further complicating this array of institutions is a multitude of sub-groups representing in various ways the interests of each of these parents. It has long been impossible for anyone to follow the meetings of these groups - much less know what is happening in them. All of this has led to a gigantic Tower of Babel where nobody completely knows what is going on and few - if any - can even understand all of the acronym-laced language.

THERE'S TOO MUCH ALLEGIANCE TO PAROCHIAL INTERESTS

Too many people who are charged with making the improvements have no *real* motivation to do so. In fact, many of them have an overriding motivation to maintain the status quo.

Few (if any) organizations have as their mission the charge of making things better for somebody else while endangering something they hold dear. And yet, in order for some desired changes to occur in the world's airspace system, some compromising is going to have to occur.

THERE'S NO OVERALL IMPLEMENTATION PLAN, ORGANIZATION OR ACCOUNTABILITY

Complicating the lack of progress toward FANS even more is the fact that no organization has overall responsibility for coordinating and leading the overall effort.

Today, no organization seems to have the proper composition to design and implement desired new technology within a reasonable and economic time frame. (Some would argue that ICAO should play that role. However, ICAO is a poor candidate for this kind of work because of its built-in and incumbent bureaucratic process. ICAO, like CAA organizations, are better suited to *endorse* rather than *invent* new air traffic concepts, technology or procedures.)

THERE'S TOO MUCH BUREAUCRACY

It is traditional that air traffic functions are controlled, maintained and improved by government. In the United States, of course, the agency responsible is the FAA. While the FAA has a proud legacy of overseeing decades of aviation growth and unprecedented improvements in transportation safety, few are particularly proud of its recent record of adapting new technology into service. Why can't the FAA respond faster and better to the bountiful technology buffet which it is offered?

This question is not meant to be mean-spirited or cynical. The Clinton Administration, itself, is recognizing the inability of government to manage some things well and has acknowledged this shortcoming publicly. In fact, Vice President Gore is presently leading the Administration's effort to reduce government fossilization by "reinventing government." A number of career government officials have also asked this question in various ways: Why can't government do business functions well?

Management professor Peter Drucker claims that there are two basic reasons for this: (1) Governments by their very nature are political and not economic, and (2) because governments must respond to various conflicting constituencies, they can't manage controversial or "hard" projects well where tough decisions can cause some interests to lose.

But government isn't the only victim of bureaucracy. There is enough of it to go around in any large organization. It is the organization model which is flawed, not the people within it. This bureaucratic model is under attack from a legion of management experts. But, it isn't only management consultants who criticize it, it is also effective managers such as Jack Welch, the CEO of General Electric. The bottom line is this: The bureaucratic model, sometimes also referred to as the hierarchical model - like "division of labor" - doesn't work well in knowledge-intensive work activity.

THERE'S TOO MUCH RELIANCE ON VOLUNTEERISM

Volunteer service is a noble pursuit. Yet, it has limits and will not accomplish the desired FANS if relied on too heavily.

A common complaint in many industry forums today is that the users don't attend. Yet many user organizations want to attend to development issues but simply can't.

Why is this so? The answer is obvious to any close observer of the current economic situation which the world's airlines find themselves. *They can't afford it*. Furthermore, there is little hope that this situation will change for a number of years.

THEREFORE, THESE RESULTS OCCUR

- Airlines and other users have no control over program management or progress. This is especially true in the development of new ATC infrastructure.
- Airline and other user inputs, validation and program review are missing or inconsistent.
- Operational innovation and procedural solutions are too infrequently applied while technical solutions are often overly elaborate.
- There is no real urgency to finish anything.
- Development dollars are wasted.
- Operational improvements which could save the airlines billions of dollars per year languish.

POSSIBLE SOLUTIONS

The challenge which aviation faces in managing the movement to the new FANS is indeed awesome. But there is a way.

1. **Reorganize using team concepts rather than the traditional groups.** The teams must include the user community. Pilots and controllers must be involved. The teams could be composed of avionics vendors, ATC equipment vendors, airframe OEMs, airline operations and engineering personnel, and selected ATC experts. It will be up to the team organizers to determine the composition of their teams, but it is expected that innovation skills will be at least as important as subject matter expertise.

2. **Ensure that the teams are fully funded.** Volunteer work won't "cut it." Full time professional work must largely supplant the continuing volunteer work which will take place.

3. **Empower the teams to make decisions which will be honored.** This will require interest groups to give up the right to veto decisions of the team. Difficult decisions in the past, such as reducing cockpit staffs to two rather than three, was accomplished because of an agreed to precondition that various interest groups would abide by the ultimate decision. Such a decision-making body is worth exploring in this case. If implemented, however, it needs to be staffed with experts of exceptional credentials and led by extraordinary facilitators with profound sensitivity and judgement.

4. **Demand accountability.** The teams should be managed with schedules and other tangible methods of reporting results. Complementing the overall decision-making body should be the overall program management entity responsible for getting the job done, on schedule and within budget. This function will also require a team of extraordinarily gifted managers with extraordinary project management skills.

5. **Assign appropriately sized projects to the teams.** Do not make the assignments so large that new bureaucracies need to be created to organize them.

6. **Cross fertilize the teams.** Ensure that each team is knowledgeable in a high-level way about the activities, objectives, progress and breakthroughs of the other teams.

7. **Consider competing team projects.** Especially when alternative technical solutions are available, competition may be highly effective in promoting the best solution in the most economical way. Some specific tasks might be handled this way, such as a new oceanic workstation or even a new oceanic control center.

8. **Set goals properly.** The purpose of the effort is not to

protect sacred cows or to advance parochial interests. It is to determine, develop and put into operation, new air traffic management solutions in the most efficient way possible.

FUNDING POSSIBILITIES

Airlines will be motivated to invest in new technology only when economic benefits can be clearly realized and when there is a reasonable time correlation between the payout and payback. But in the meanwhile, where will the funding for development come from? Three general possibilities suggest themselves:

> Government. Governments can gain by allowing competitive innovators to take more responsibility for modernizing their air traffic systems and thereby improving their transportation infrastructures.
>
> Private industry. Manufacturers and vendors gain because it offers a way to substantially reduce development time and therefore increases their return on investment.
>
> Partnerships, consortiums or other alliances between government and private industry.

The first two, government and industry investment are traditional and well known. The partnership idea is more novel and has some particular interest to Northwest and other airlines. It has also been discussed and apparently will be recommended by the National Commission to Ensure a Strong Competitive Airline Industry.

Currently the government is supporting "partnership" programs with the airline industry in at least two ways:

> (1) The Technology Reinvestment Project for defense technology conversion, administered by the Advanced Research Projects Agency (ARPA).
>
> (2) A possible new Aeronautical Telecommunications Network (ATN) corporation sponsored by the FAA with the cooperation of the Air Transport Association (ATA).

Northwest has teamed with three private industry groups which have submitted proposals to ARPA for an advanced landing system using satellite navigation and enhanced vision imaging; an electronic maintenance diagnostic and reporting tool to reduce maintenance delays; and a computerized system of recovery after unavoidable weather disruptions.

Successful privatization initiatives should be investigated for possible inspiration and guidance. There are likely models which may be applied which could show the path to win-win outcomes for all the constituencies of such a program - public and private.

Borrowing mechanisms should also be explored. Repayments can come from future savings. User fees and pay-as-you-use plans can be possible vehicles to accomplish this. Care needs to be used, however, to not add debt to airline balance sheets or to penalize users for unrealized benefits.

SUMMARY

Airlines and other aviation users want the benefits of new satellite navigation and communication technologies. They also want to migrate at the earliest possible time to the new FANS.

Investments, however, must be aligned with the benefits. Airlines cannot afford a "benefit gap." Therefore, if these efficiencies for the public are going to happen soon, a new method of achieving more reasonably rapid implementation must be found.

Exploring new organizational structures and innovative funding techniques are seen as possible solutions.

PROFESSIONAL AIRWAYS SYSTEMS SPECIALISTS

Administrative Office
1220 North University Drive
Plantation, FL 33322
Phone: (305) 424-7577
FAX: (305) 424-9377

Legislative Office
1150 17th Street, Suite 702
Washington, D.C. 20036
Phone: (202) 293-7277
FAX: (202) 293-7727

Howard E. Johannssen, *President/Chairman*
Marvin E. "Bud" Long, *Vice President/Vice Chairman*
A Division of District No. 1—MEBA/NMU (AFL-CIO)

TESTIMONY OF HOWARD E. JOHANNSSEN, CHAIRMAN

PROFESSIONAL AIRWAYS SYSTEMS SPECIALISTS (PASS)

BEFORE THE

HOUSE COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION

SUBCOMMITTEE ON AVIATION

JULY 28, 1993

Chairman Oberstar and Members of the Subcommittee:

My name is Howard Johannssen, and I am the National Chairman of the Professional Airways Systems Specialists (PASS), District No. 6 - MEBA (AFL-CIO). Thank you for allowing me the opportunity to testify before you today concerning current and future uses of satellite technology in the aviation industry.

Since 1977, PASS has proudly served as the exclusive representative for more than 10,000 Technical and Aviation Systems Specialists employed by the Federal Aviation Administration (FAA). Presently, our bargaining unit consists of Flight Standards Aviation Safety Inspectors (AFS), Office of Aviation Systems Standards Flight Check Pilots and Crew (AVN), and Airway Facilities Maintenance Technicians (AF) who, on a daily basis maintain, repair, inspect and certify all of the equipment used in the National Airspace System (NAS).

Today, many private and public groups have emerged within the aviation industry which are attempting to expedite replacement of current NAS navigation systems with either a Global Navigation Satellite System (GNSS) or a Global Positioning System (GPS). In fact, in their attempts to obtain support for a rapid GNSS/GPS implementation plan they advertise that Department of Defense (DoD) "satellites are nearing operational service and are offered free to the world" and that DoD satellites "improve safety, effective traffic separation and precise instrument flight."

Undoubtedly, these various groups are motivated foremost by a profit incentive. Yet, after analyzing their actions and their intentions, PASS believes that their goals are, for the most part, honorable and well-directed. Nevertheless, we also firmly argue that safe implementation of a GPS system cannot be accomplished without full agreement by both government and industry on system standards, procedures and frequency allocation. Therefore, we seek to be included in the GPS planning and implementation processes.

Currently, the FAA -- in conjunction with aviation groups -- is sponsoring a "proof of concept" approach for dealing with the experimental GPS systems. Once this approach is tested and verified, we believe that many short and long-term benefits can be achieved. Under investigation now is a GNSS In-Service Test (GIST) FAA sponsored project called Project DFW (1) (PD) which is being conducted at Dallas Fort Worth (DFW) and Alliance (AFW) Airports. According to its stated purpose, "this project will provide for the demonstration of a Global Navigation Satellite System (GNSS) with the capability of performing precision approaches and landings."

While this project appears to ambitiously cover all aspects of precision approaches, data is only being gathered on Category I (Cat I) approaches, the use of Differential GPS (DGPS) and a follow up for 3 Dimensional (3D) technology. Hence, while the data may appear to fulfill expectations, many challenges could arise since Category II and Category III operations may pose technical difficulties which are significantly different than those of Category I.

To date, some problems have already arisen in this procedure and in other planning projects being conducted by the FAA. In fact, until recently, the FAA's technical work force -- our Airway Facilities employees -- had been entirely excluded from the GPS planning and testing processes. Yet, the Agency's internal documentation states that "...augmentation of GPS may require the expenditure of funds for additional space and/or ground stations..and may require publicly funded differential stations. If so, these facilities will have to be sponsored and procured by Airway Facilities."

Without a doubt, Project DFW is extremely promising and highly valuable. However, PASS believes that our Systems Specialists must be allowed to participate in every aspect of this project and must be given the opportunity to assist in the determination of safe parameters for the GPS in private and commercial aviation. Therefore, we urge the FAA to include all facets of the aviation community in this initial test project and to provide the necessary resources for full exploration of the GPS beyond military and general aviation operations.

Unquestionably, our AF members have the talent, knowledge and ability necessary to maintain our current systems and to install, to maintain and to certify future systems within the FAA. Additionally, our Flight Standards and Aviation Systems Standards members have the regulatory and avionics experience required for successful completion of testing and procedures for GPS. As you can see, development of procedures and equipment for satellite-based systems should incorporate representation from all disciplines within the FAA.

Through our affiliation with many international aviation organizations, including the International Transportation Federation (ITF), Public Services International (PSI) and the International Federation of Air Traffic Safety Electronics Associations (IFATSEA), PASS has become aware of many concerns within the international aviation community which also pertain to the implementation of a GPS system. From my discussions with representatives of these organizations, which represent ATC professionals, Safety Inspectors and Pilots abroad, I have found a mixed spectrum of fears, particularly with regard to the use of a GPS system that would rely on the current U.S. DoD satellite system.

In our opinion, without International Civil Aviation Organization (ICAO) approval for the use of U.S. GPS satellite navigation, the FAA will be required to operate dual facilities (ground equipment and satellite) at all U.S. international airports. Therefore, there is an urgency for full international agreement and cooperation on the use of a GPS system. Undoubtedly, without international support, implementation of a GPS system would be very costly and would require an enormous amount of equipment and personnel.

As we prepare to rely more and more upon satellite technology, our primary focus must remain on the FAA and on the way it will do business in the future. At present, the Agency serves the users of the NAS in a remarkable way. In our opinion, there is no other federal agency that can compare to the FAA's record or level of accomplishment; the mission of the FAA is carried out safely and efficiently because the people and the equipment are proven. Thus, in order to preserve its solid reputation, as well as the integrity of the flying skies, the FAA must strive to achieve the cooperation and the concerted efforts of the entire aviation community; for, only with substantial teamwork will the FAA be able to ensure the safety of the National Airspace System as we embark upon future navigation systems.

Testimony of
Christopher R. McCleary
American Mobile Satellite Corporation

Mr. Chairman and Members of the Subcommittee, my name is Chris McCleary. I am Vice President of Sales and Marketing for American Mobile Satellite Corporation. Thank you for the opportunity to tell you about AMSC and its plans to provide satellite service to the aviation industry.

AMSC is the entity licensed by the Federal Communications Commission to construct, launch and operate a Mobile Satellite Service system for the United States. The FCC authorization specifically includes permission to provide the facilities for aeronautical communications by satellite, including what is called "AMSS(R)" or aviation safety communications.

AMSC's owners, the largest of which are GM/Hughes Electronics, Inc. and McCaw Cellular Communications, Inc., have already raised and invested over $375 million in the construction of what is expected to be a $500 million satellite system. The first satellite, to be launched in mid-1994, will be the most powerful commercial satellite ever launched, with the capability to provide two thousand channels of mobile voice communications to terrestrial, maritime and aeronautical users.

Despite the success of cellular and other terrestrial mobile radio technologies, as much as half of the land mass of the United States for the foreseeable future will remain unserved by these technologies. This is where the satellite comes in. The satellite's footprint will cover North America (including up to 600 miles offshore and in the Caribbean), filling in the often sizable gaps among terrestrial systems. This means that for the first time vast rural and remote areas will have access to modern mobile communications for fire, police and ambulance service and, of particular importance to the Public Works and Transportation Committee, the U.S. interstate transportation industry will have seamless voice communications for trucks, trains, barges and air freight travelling throughout the United States.

AMSC is also strengthening the American economy in its procurements. The AMSC satellite bus is being built by Hughes Aircraft Company in El Segundo, California. Westinghouse Electronic Systems is designing the Network Operations Center and General Dynamics is providing the satellite launch.

Upon the launch and deployment of the AMSC system, the aeronautical industry will be able to utilize a new, advanced communications facility for air traffic control (ATC), airline operations communications (AOC), airline administrative communications (AAC), and airline passenger communications (APC). Certain AAC and APC services will be provided using the standard AMSC ground facilities. ATC and AOC services will require specialized ground facilities. AMSC is working with potential service providers such as Aeronautical Radio, Inc. and IDB Aeronautical, Inc. to develop these facilities. AMSC is also developing the capability for individual airlines to establish their own private networks using dedicated ground facilities and AMSC's space segment. The cost of terminal equipment and user charges will be within reach of everyone from the large carriers to the general aviation enthusiast.

Pursuant to FCC requirements arrived at with the participation of the Federal Aviation Administration, AMSC will give priority to aviation safety communications. AMSC will reserve a pool of channels for AMSS(R) communications and will expand that pool as demand requires, including preemption of other lower priority users if necessary. This arrangement provides a win-win situation for all involved. Radio frequencies that are in high demand will be put to use efficiently on a commercial basis to serve all users, and the aviation community will have access to those facilities on a priority basis without the massive capital requirements of constructing its own high-risk satellite system. Earlier efforts to develop stand-alone satellite systems for the aeronautical community, in the 1970's and the 1980's, demonstrated that such systems are not economically viable.

AMSC is extremely enthusiastic about the value that satellites will bring to the aviation market. Satellites can and will play an important role in providing cost-effective communications that will improve the safety and efficiency of the industry. We look forward to returning in a few years to provide you the empirical evidence of those benefits.

July 28, 1993

Current Address:

1150 Connecticut Avenue, NW
4th Floor
Washington, D.C. 20036
202-331-5858

After August 6, 1993:

10802 Park Ridge Boulevard
Reston, Virginia 22091
703-758-6000

General Aviation
Manufacturers Association

Suite 801
1400 K Street, N W
Washington, D C 20005-2485
(202) 393-1500

Statement of

David W. Mineck
Director, Advanced Systems

Collins Commercial Avionics, Rockwell International

on behalf of the

General Aviation Manufacturers Association

before the

Subcommittee on Aviation

House Committee on Public Works and Transportation

July 28, 1993

on

Future Uses of Satellite Technology in Aviation

Good morning Mr. Chairman and members of the Subcommittee. I am David Mineck, Director of Advanced Systems, Collins Commercial Avionics, Rockwell International. Mr. John Girotto, President of Collins Commercial Avionics, serves as Chairman of the Airport\Airway and Operations Committee of the General Aviation Manufacturers Association (GAMA). Today, therefore, I will speak on behalf of both Collins Commercial Avionics and GAMA.

GAMA represents United States companies that manufacture business, commuter, and personal aircraft, engines, avionics and other component parts. GAMA was an advisor to the U.S. delegation at the ICAO Tenth Air Navigation Conference and GAMA has been involved in numerous Global Navigation Satellite System (GNSS) task forces and working groups. GAMA is a strong advocate of an early transition to GNSS.

Headquartered in Cedar Rapids, Iowa, Collins Commercial Avionics manufacturers a complete line of communication, navigation and flight control avionics systems for general aviation, airline, and military aircraft. Our parent company, Rockwell International, has been a key member of the GNSS implementation team since its inception. Rockwell Space Division designed and built all the GPS satellites in orbit. Rockwell's Collins Avionics and Communications Division has designed and/or built the majority of the DOD production equipment for avionics, shipboard and vehicle/manpack applications. Rockwell's Digital Communications Division is a leading supplier of GPS modules to Original Equipment Manufacturers in a variety of commercial markets. Collins Air Transport Division is currently developing, marketing and producing satellite-based communication systems (SATCOM). Collins Commercial Avionics Division has also been a leader in applying GPS to the ground transportation industry, including trains and trucks.

There is no doubt that we stand at the beginning of a new era in aviation. Our customers, from airlines to business aviation to personal-use aircraft, are already installing GPS receivers. Many in our industry believe that the impact of GNSS on aviation will be similar to the introduction of the turbo-fan engine. The question, therefore, is not whether we should transition to GNSS ... but how can we make a smooth and efficient transition, gaining the most utility for the users in the process.

Today, I will first discuss the applications and benefits of GNSS implementation. Then, I would like to point-out what we believe has gone "right" with the transition thus far. In many respects, we have done well. But there are several troublesome technical and political areas ahead, and I discuss each briefly.

Applications and Benefits of GNSS Implementation

The industry has documented the potential cost savings available to all users of a Global Navigation Satellite System (GNSS), which includes datalinks and SATCOM. The primary benefits are derived from improved navigation accuracy, thereby increasing both enroute and terminal area capacity. When GNSS is fully implemented, we should be able to achieve close to Visual Flight Rule (VFR) operational capacities during actual Instrument Meteorological Conditions (IMC).

But other benefits derived from GNSS also contribute substantially to improving operational safety. Near-precision or precision approach guidance can be made available at relatively little cost to virtually every runway, anywhere in the world. Terrain avoidance can be improved when GNSS position information is used in conjunction with internally stored terrain maps. Combined with data link, separation assurance can be improved both in-flight and during ground operations. In addition, airport vehicle management can be substantially improved under all weather conditions.

The application of GNSS and datalinks to and from the aircraft will allow the air traffic navigation and management ground structure to eliminate many current navaids, such as VOR, DME, ADF, ILS and potentially MLS. (As the number of published GPS approaches increases, however, we may actually increase the need for new runway lighting systems.) The opportunity exists to develop entire air traffic and management systems at relatively low cost in those parts of the world that are currently without services.

The costs of equipping an aircraft for IFR flight will ultimately be reduced as GNSS replaces a number of currently required sensors...VOR, DME, ADF, ILS, MLS, IRS and other long range navigation aids.

GNSS Program Successes

Fortunately, some of the foundation for a successful transition to GNSS has been laid. First, the industry has already made significant technical progress in defining how to reap the benefits of Satellite technology. GPS technology is ready today, and in many ways technology has pushed the transition process. This is the opposite of the common pattern where a transition plan pushes technology. And it is this difference that accounts for much of industry's enthusiasm for the GNSS transition.

An internationally approved, global civil aviation system concept designated FANS (Future Air Navigation and Surveillance) currently exists. The Aeronautical Telecommunication Network (ATN) has been defined, providing a basis for digital communications between the aircraft, air traffic management and airline operations networks. Standards have been established for SATCOM that will soon be providing both airplane operational communications as well as improved passenger services.

The FAA should be commended for its timely overlay of GPS on most of the nation's existing non-precision approaches and for allowing early enroute IFR navigation with GPS. Another GAMA member company, Jeppesen, assisted the FAA by providing the technical expertise to complete the overlay project on time. The FAA created the regulatory infrastructure for these non-precision approaches and had it in place before the IFR navigation GPS receivers arrived in the market. This should be the model for future GNSS development.

Demonstrations of GNSS with datalink for enroute and approach are being conducted by industry and regulatory agencies throughout the world. The aviation industry is anxious and ready for the benefits of satellite technology, but several key issues remain to be resolved.

Key Issues To Be Resolved

GNSS Program Coordination. Significant progress is being made on many of the technical and political issues associated with moving to a satellite based aviation system, but the current plans and infrastructure are causing significant delays in allowing the industry to receive the full benefits of GNSS. We are frustrated by the fragmented nature of industry/government implementation efforts. We need a single authoritative body that encompasses all FAA GNSS efforts and key elements of the aviation industry, including airline/airplane operators, airport operators, airplane/equipment manufacturers and other regulatory agencies. This body should be empowered to carry-out an integrated GNSS implementation plan.

Datalink Standards. Standards must be developed for datalink of differential information to the airplane and position/identification information from the airplane. While many alternatives exist, consideration must be given to the cost impact on small, general aviation aircraft. We must ensure that a cost effective, technically sound solution is adopted. Certification standards must be clarified so that the manufacturers can avoid the significant expense of multiple software certifications to meet evolving standards. With today's digital technology, a substantial portion of the product cost is associated with software development and validation.

Integrity Warning. A satellite integrity warning approach must be defined and adopted that is equivalent to and consistent with current operational requirements, without overly restricting the availability of GNSS at any location. Immediate warning of GNSS failure is generally required, and the industry would prefer to have monitoring and warning generated by systems internal to the receiver, not by external systems.

Operational Integration. Industry has been focusing primarily on the technical performance of satellite-based systems. Operational integration approaches must be defined that address air traffic management procedures so that a mixed fleet (GNSS equipped and non-equipped) can inter-operate, while still providing full benefits to those that are GNSS-equipped. Experience with Flight Management Systems (FMS) has shown that many operators have not received the full benefits of FMS-equipage because the air traffic management system was not prepared to manage a mixed fleet.

The operational integration must also consider the impact on aircraft systems. The costs to refit the existing fleet are significantly increased if operational requirements demand extensive changes to already-installed systems.

Human Interface. Crew interface considerations must also be defined. Many of the benefits of increased capacity will require an approach that gives the pilot the same situational-awareness confidence under actual IMC as that enjoyed under VFR. Air traffic controllers must also be trained to understand the new capabilities of GNSS-equipped aircraft.

Precision Approaches. The suitability of GNSS for Precision approaches must be established as soon as possible. The question could change how the FAA plans to implement the Microwave Landing System (MLS), with its associated international agreements. Of particular importance to general aviation is whether GPS will allow "near-precision" minimums (near 200 ft. AGL). Also important is the cost of installing local differential GPS for "precision" approaches.

International Standardization. Increased airspace efficiency must be achieved on both a domestic and international basis. This requires inter-operability, coordination of technical standards and implementation timing.

GPS Cost Allocation. The question of GNSS system control and cost allocation must also be resolved soon. Most of the cost/benefit analyses performed to date do not include additional GNSS user fees. User fees based on real-time ATC system use are already an international problem. One major airline recently reported that for a particular flight leg, the sum of the individual country user fees exceeded the cost of the fuel for the flight. Determining user fees for GPS will be extremely difficult, as aviation users will represent less than three percent of all GPS users. In general, we believe that safety of flight services, such as navigation aids, should not be financed by "As-you-fly" fees because this structure discourages the use of safety equipment, degrading the margin of safety.

Conclusion

The world looks to the U.S. for leadership in transitioning to GNSS. We have the technology. We must now ensure that the regulatory process keeps pace and that we develop a single, world-wide system of satellite-based navigation and communication.

I appreciate this opportunity to appear before this Subcommittee. I would be happy to answer your questions.

STATEMENT OF

JOHN O'BRIEN, DIRECTOR

ENGINEERING AND AIR SAFETY

AIR LINE PILOTS ASSOCIATION

BEFORE THE

SUBCOMMITTEE ON AVIATION

COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION

U.S. HOUSE OF REPRESENTATIVES

JULY 28, 1993

USE OF SATELLITE TECHNOLOGY TO IMPROVE THE AVIATION SYSTEM IN THE UNITED STATES

Good morning, Mr. Chairman and members of the subcommittee. I am John O'Brien, Director of the Engineering and Air Safety Department of the Air Line Pilots Association (ALPA). ALPA represents the professional interests of 42,000 pilots flying for 44 airlines.

We appreciate the opportunity to appear before you and provide comments on the use of satellite technology to improve the aviation system in the United States. Like many other members of the aviation community, we believe that satellite technology will provide significantly enhanced capabilities in communications, navigation and surveillance.

These multiple uses and benefits have been adequately identified by many creditable government and industry sources. Rather than reiterating the uses and benefits associated with satellite technology, I would like to describe a concern we have. Our concern is that we, the industry and government, through lack of adequate resources, may not be able to mount the effort required to achieve maximum beneficial use and earliest possible implementation of satellite navigation, communication and surveillance capabilities. So from our perspective, the issue is how do we solve this resource problem so we can achieve these benefits as quickly as possible.

The effort required on the part of industry and government has many components. I would like to focus on one of the most critical. This component involves defining the specific details of the operational requirements for both airline and general aviation use of satellite technologies. Then, the criteria that will be used by FAA for operational approval of hardware, software and operational procedures designed and/or developed by avionics manufacturers and aircraft operators to meet these operational requirements must be defined.

Today, government advisory committees and industry organizations, such as RTCA, play a very important role in the development of guidance material that eventually becomes the FAA certification criteria or other related guidance information for manufacturers and operators. This process is also used in developing industry consensus on technical data which will be used by FAA in the establishment of Technical Standard

Orders (TSOs) or other regulatory or guidance material for the certification and approval process I previously mentioned.

We are well aware of the significant effort undertaken by RTCA to identify the most promising applications of satellite technology for aviation purposes and reach an industry-wide consensus on how best to integrate them with today's air transportation system. RTCA membership includes all of the necessary government and aviation industry representation to accomplish the consensus building and data development work required in order to obtain early implementation of satellite technology.

RTCA is also a government advisory committee and has played a very important role in developing standards for many communication and navigation systems. However, RTCA resources are limited because of the cap on spending that has been levied on FAA advisory committees by DOT. Also, because our industry is in poor financial health at this moment, it is difficult to justify significant industry participation in RTCA activities without a clear indication that such a commitment will lead to practical results.

Now back to our concern. If the picture I have just painted is accurate, and I believe it is, how are we to proceed with rapid implementation of satellite technologies for our industry -- technologies which will provide significant safety benefits as well as operational efficiencies which are certainly needed in view of the economic situation we are presently experiencing.

First, FAA must be allowed to fund advisory committees such as RTCA in a manner which is responsive to the needs of government and industry.

Second, clear and definitive direction must be established by FAA, in concert with industry, in the development of a road map for early implementation of satellite technology. One of the important steps in this process is currently underway. Decisions which will permit the systematic and orderly transition to digital communications are being developed by RTCA Task Force II. This Task Force is a natural follow-on from the earlier RTCA work to identify applications of satellite technology. However, much remains to be accomplished.

Third, pending adequate FAA advisory committee funding and development of a clear road map for early implementation of satellite technology, our industry must be willing to commit resources for the development of criteria for certification and guidance material. We are one organization who is ready to make that commitment today.

In summary, we believe that present satellite systems have significant communication, navigation and surveillance capabilities. However, these capabilities are not being used in a manner that provides maximum benefit to aircraft operators or government agencies who must provide services to these operators. Very little pure research or engineering is needed in order to greatly increase the use of these capabilities. What is needed is rapid definition and development of industry consensus on the operational requirements and on the technical data which will be used by FAA for the certification and operational approval of the hardware, software and operational techniques associated with these requirements. The Subcommittee on Aviation can play an important role in this process.

This completes my statement, Mr. Chairman, and I would be happy to answer any questions that you and the other members may have.

TESTIMONY

SECRETARY OF TRANSPORTATION
FEDERICO PEÑA

HOUSE PUBLIC WORKS AND TRANSPORTATION COMMITTEE
SUBCOMMITTEE ON AVIATION

I am pleased to appear before this committee today to provide my vision of a truly revolutionary technological achievement which I believe will produce major benefits for the industry and commerce of the United States. As civil use experience with this technology develops, these benefits may extend to mass consumer markets affecting a large portion of U.S. households. Because of the nature of this technology, benefits have already been extended to the far corners of the world, extending the good will of the people of the United States in a way that was never before possible.

With me today to present detailed information on FAA's planning, research, and development for aviation use of the Global Positioning System (GPS) are Martin Pozeski, Associate Administrator for System Engineering and Development and Anthony Broderick, Associate Administrator for Regulation and Certification in the Federal Aviation Administration.

GPS, begun in the early 1970s, is a space-based positioning and navigation system. GPS signals are continuously available on a worldwide basis in any weather. The satellites are located 11,000 nautical miles above the earth. To access the system, users have only to turn on a GPS receiver, like a normal radio, with the antenna exposed to the sky.

GPS provides the greatest opportunity to enhance the air navigation system since the introduction of radio-based navigation more than 50 years ago. The impact of satellite based navigation represents an enormous potential economic benefit to the U.S. aviation industry--perhaps billions of dollars a year. The civil use of GPS for oceanic and domestic en route flight offers significantly better navigation accuracy than previously possible. When combined with other systems, it will allow a pilot to fly an optimum route to a destination, subject only to weather and the presence of other aircraft. This optimum routing will provide considerable time and fuel savings in managing the rapidly expanding oceanic and domestic en route air traffic.

GPS has a wide range of applications in other transportation sectors. In the space program and the growing commercial space industry, GPS is used to satisfy positioning and timing requirements for earth-orbiting space systems, including Space Shuttle operations.

GPS will provide marine navigators with the first precise, worldwide, continuous positioning and timing service. As a result, commercial shipping will be safer, more efficient, reliable, and economical. GPS, augmented with differential signals, will satisfy the stringent marine accuracy requirements for harbor and harbor approach navigation, that have previously been unattainable with other radionavigation systems.

Land applications of GPS are expected to comprise the largest category of GPS users. Although not traditional radionavigation system users, they are expected to employ various systems being developed to enhance the economic efficiency and safety of all land modes of transportation. Examples of applications are:

- Intelligent Vehicle Highway Systems (IVHS), will combine GPS with communications, controls, navigation, and information systems to improve highway safety, ease traffic congestion, and reduce harmful environmental effects.

- Vehicle tracking systems will use GPS for commercial and transit fleet management, hazardous material monitoring, tracking and controlling movements of railroad equipment, and automated dispatch of fire, paramedic and police units.

- GPS is also used in surveying, telecommunications and electric power synchronization, agriculture and forestry, census taking, meteorological radiosondes, and backpacking.

It is too early to say whether consumer markets will develop to the point where a GPS receiver is as common place as the radio receiver is now in private automobiles. However, it is clear that if such a market does develop, we are looking at very large numbers of installed units and individual users.

The U.S. Coast Guard has established a unit to provide support and assistance to civil users of GPS, including both transportation and non-transportation applications. The Coast Guard is also proceeding with research and development of implementation of GPS for marine users. The Coast Guard's efforts, along with those of FAA, are providing the leadership necessary to promote the full civilian use of this existing technology.

GPS was developed by the Defense Department at a cost approaching $10 billion. Even before becoming operational, GPS proved its worth to the national defense in the Desert Storm operation. However, because of its potential value to civil users, and in recognition of the significant national security implications that may be associated with its widespread civilian availability, Secretary Aspin and I have formed a joint task force to investigate options for the future management of GPS. We want to ensure that the full potential civil benefits are, in fact, made available to the public, while preserving the national security advantages of GPS for military uses. I expect to receive the Task Force's recommendations this Fall.

I commend your interest in this important subject, Mr. Chairman, and we look forward to working with you to assure that the full benefits of GPS are rapidly made available to civil aviation and the entire transportation industry.

NORTH AMERICA ACI
AIRPORTS COUNCIL INTERNATIONAL
"The Voice of Airports"

Statement of
Siegbert B. Poritzky[†]
Senior Vice-President, Technical Affairs
Airports Council International - North America
before the
Subcommittee on Aviation
House Public Works and Transportation Committee
July 28, 1993

The Value of GNSS/GPS to the Improvement of Airport Operations

From the standpoint of air traffic management, the dynamic capacity of the airport and terminal area ATC system are inextricably linked. Moment-by-moment knowledge, by the ATC system, of airport capacity determines the effectiveness of the air traffic management system.

The role the busy airport itself plays in creating (or hampering) system efficiency is not hard to discern. An FAA study, now several years old but still valid, looked at what were thought to be realistic, not theoretical, expectations of benefits from technological improvements in the IFR use of the airport resource[1]:

> Multiple independent approach concepts can yield 44%-100% increases in IFR capacity.
>
> Reduction of separation requirements between approaches for multiple dependent approaches can yield 25%.
>
> Reduction in longitudinal separation standards can yield 15%.
>
> Reduction in system variabilities, i.e., by automation, can yield 12%-16% capacity.

Gains well worth striving for! Of course, not all these gains can be expected in every situation, and several depend on real integration between the enroute and terminal area ATC system, but the potential is there to be exploited.

[†] Before joining the Airports Council International - North America, the witness spent ten years at FAA during the formative period of GPS/GNSS assessment and policy-making, coming to FAA as Director, System Engineering Management after many years in the Air Navigation & Traffic Control organization of the Air Transport Association. He was the member nominated by the United States on the ICAO Future Air Navigation Systems Committee. In 1984, he was permitted to introduce to ICAO FANS the concept for what became GNSS. He serves on the Board of RTCA, the government-industry standards-making group, as a representative of the airport community, and co-chaired the Requirements portion of the recent RTCA Task Force 1, asked by the FAA Administrator to recommend the transition strategy for GNSS. He is currently the co-chairman of the RTCA Task Force 2 working group on institutional and transition issues related to digital communications, and had the task of coordinating a recommendation to FAA on the optimum GPS/GNSS differential transmission communications medium.

We realize that in many places even the forecasted gains from technology and system management will not be enough. That, of course, is why the Airport Improvement Program (AIP) and Passenger Facility Charges (PFCs) are crucial to building the new capacity only new runways and new airports can create.

GNSS/GPS will be a major element in the technology of airport and system capacity, and in the essential coupling of the airport and the air traffic management (ATM) system.

In a recent action[2], the Board of Directors of ACI-NA recognized that system integration and better information flow are the keys to a modern aviation technical infrastructure, and endorsed an integrated policy with several elements:

GNSS - The Global Navigation Satellite System, to which GPS is the major U.S. contribution, is expected to be the primary navigation system (enroute and, especially, in terminal areas) along with the Microwave Landing System (MLS) for Category 2 and 3 final approach and landing guidance. GNSS alone is expected to serve all navigation needs for many aviation system users. Differentially-augmented GNSS is likely to support operations to at least Category 1-equivalent minima.

ILS/MLS - ACI-NA supports and urges the early completion of a simpler-than-currently-specified, but Category 2/3-capable, MLS. MLS may now be designed to provide its service in a ±12 degree azimuth front coverage sector, and will no longer require Precision DME.

GNSS for Airport Surface Operations - GNSS-based airport surface traffic management would significantly improve airport operations and is the approach of choice for airport surface operations.

GNSS position determination accuracy could increase runway capacity in bad weather at airports that have converging or parallel runways where spacing does not permit parallel approaches with current navigation aids. GNSS could provide precise navigation guidance for drivers of emergency vehicles, snow-removal equipment, and probably others. Differential GNSS/Automatic Dependent Surveillance may be capable of providing the data source for separation assurance functions now provided by precision runway monitor (PRM) systems.

GNSS vs. Terrestrial Radar Sensors - Development of Automatic Dependent Surveillance (ADS) techniques for terminal areas, using GNSS (especially terminal areas where VHF communications are difficult and in those where radar can not be justified) is supported for the future.

The need for terminal area weather information, winds aloft on the approach paths and in their vicinity, microburst detection, wake vortex detection, and possibly precision runway monitoring and backup airport surface detection radar will continue to require terrestrially-based independent sensor capability.

Operational Opportunities - Early implementation of the ICAO Required Navigation Performance concept is recommended to permit evolution from the rigid approach and landing categories and obstacle clearance criteria to performance-capability-related minima of the aircraft themselves and their crews.

System Integration/Digital Communications Standards - Development of terminal and on-airport automation systems should proceed, fully integrated and harmonized with more capable air traffic management and flow management techniques. World standard, broadly-applicable digital (data link) communication, fully applicable to satellite and terrestrial communications, is crucial.

It is not hard to grasp, from these airport policy views, that the days of separate consideration of ATC/ATM improvements and airport operation technologies are gone. And good riddance, if we hope to gain the real benefits from the synergism that is the key to aviation's technological future.

Some Policy Considerations of GNSS/GPS

I would like now to add some thoughts from the perspective of a former member of ICAO FANS, and as an airport member of the recent RTCA Task Forces working with GNSS.

It has been argued that geostationary satellite services are likely to be needed to make up for an inadequate number of satellites, and thus the differential service could be easily provided at low cost. This may not be a sound argument because a) between GPS and GLONASS there should be enough satellites, b) such a differential service might not be available to all users (at least partly because of the cost), and c) the accurate coverage would be restricted to certain limited geographic areas, which would injure the universality of the system. Because of the gigantic prospective GNSS user base, it would be far better to launch additional satellites for everybody if not enough satellites appear from GPS and GLONASS. The user community should do everything it can to encourage early technical integration and launch of the GLONASS system.

GPS, the $10 billion+ United States contribution to GNSS, is a major element of the GNSS system. The United States offer to work in harmony with GLONASS and other contributors was a peaceful step to help all of aviation. ICAO FANS embraced the concept, and ICAO accepted the offers of the U.S. and the CIS to make the system available indefinitely at no charge and to provide a minimum of six years notice of any change in policy. It was understood from the start that the system architecture was constructed in a way, and the implementers were willing, to have other states launch satellites within the system and thus broaden its ownership.

GNSS Availability and FAA Management

GNSS/GPS, in my view, is an example of what FAA is doing right, in which top management is fully committed to moving rapidly. That top management has shown its willingness to work with the industry in several ways, but prominently by asking organizations like RTCA to assure that industry is involved and heard as a partner in the process. Of course there will need to be continuing vigilance, pressure and involvement from the user industry to keep it moving.

It is no doubt true that the enthusiasm of FAA's top management for the coming revolution, perhaps not surprisingly, does not yet fully apply to the lower levels of FAA, in part because of the limited number of capable staff (FAA has less than a handful of satellite scientists/engineers). The differences in approach of FAA's regional organizations remains a problem that needs continual attention.

Several old arguments about GNSS availability and management, its beginnings as a military system, and other allegations that are potentially destructive to the aviation revolution GNSS can trigger, are being recycled[3]. The charges and worries are not new. They were brought up by one or two states when the U.S. first made its offer of GPS to ICAO FANS in 1984-85. The arguments had little credence, then or now.

Because GNSS will be a safety-of-life system, extreme prudence is required to assure the integrity of the system before a properly conservative FAA could approve the system for primary use. Such operations, the use of GPS/GNSS for "special Category 1" low visibility landing operations, and later application to even lower visibilities require not only very high accuracy, but demand a capability that represents the toughest challenge for satellite systems, as yet undemonstrated, of providing nearly instantaneous failure warning and annunciation. The FAA time table for these decisions may be conservative, but it would be foolish to promise specific results when the technology is not yet here. It would be equally foolish to abandon the Microwave Landing System until the capability of GNSS/GPS for low visibility operations is proved safe beyond the shadow of a doubt, and until we are sure that less sophisticated aircraft than modern commercial jetliners are not disadvantaged by such a decision.

The middle letter in ADS stands for D as in "Dependent"- automatic dependent surveillance **depends** on the aircraft navigation system performance. These new services will be acceptable only if their safety and integrity are very high. Backup services may well be required, especially for terminal area services, possibly by multi-function sensors which include Secondary Surveillance Radar (SSR) and perhaps Mode S.

Where Should FAA Concentrate its Efforts Now?

It is my belief and that of the Association I represent, that the technology of GNSS/GPS is here. It is not a futuristic R&D scheme. The task is no longer to establish whether it works, but how to implement it quickly and safely. This fact should drive FAA's efforts.

1. Perhaps the most important task now is for FAA to find better ways to develop the new procedures which GNSS makes possible. Progress has been made

already, but a better way to create thousands of new location-specific procedures is needed.

2. There has been much discussion of the GNSS differential transmission medium choice, and an early decision is essential.

3. There has been much emphasis by some users on early achievement of providing GNSS Category 1/2/3 low-visibility operations. This is laudable, and airports support the work, but it may not be the most important consideration.

The following need major attention:

4. The application of high integrity GNSS to Automatic Dependent Surveillance (ADS, in which the automatic transmission of navigation position is used to create a "pseudo-radar") and other functions will be important for GA as well as commercial aviation. The remarkable capabilities of GNSS are likely to let GNSS/ADS become a primary ATC surveillance system.

5. GNSS/ADS, which requires early decisions on the long sought-after digital communications system, is the approach of choice for airport surface surveillance and automation. FAA needs to assure itself and the industry of the performance of the system on the airport surface, and its full suitability for the future challenge.

6. GNSS may be the source of the long sought-after "talking beacon" which can continuously make the location, identification and altitude of all aircraft known to all others and the ATC system.

7. GNSS may become the data source for a collision avoidance system far simpler than the current CAS.

8. GNSS may serve as a simple, inexpensive data source for Precision Runway Monitors.

These applications are where we believe FAA needs to spend its energies now. It is important to make haste, but to do it very carefully.

9. There is another area where FAA attention, analysis, and evaluation is essential. The very characteristic which makes GNSS/GPS so attractive, its world coverage from the surface up, also makes its necessarily weak signals vulnerable to interference and to intentional or unintentional jamming. This is a matter, not for panic, but for prudent actions and precautions. All aviation radio systems, including ILS, are subject to interference and jamming by skilled, determined persons, and continuous vigilance is required. FAA and DOT, well aware of this issue, need to work actively with DOD, FCC, NTIA, ITU and others and come to closure soon on the means to assure that the system is adequately protected from interference. Standards-setting bodies, already at

work on this issue in RTCA and elsewhere, need to assure that receiver designs provide adequate protection against interference. In considering critical applications of GNSS/GPS, FAA and the industry need to agree on the limitations and the necessary precautions against unlawful interference with the operation of the system.

It is important not to blow this problem out of proportion. The existence and use of GLONASS along with GPS to make up the Global Navigation Satellite System (GNSS) envisioned by ICAO FANS, which offers so many other benefits to satellite navigation, also helps minimize the potential impact of unlawful interference attempts. Well-designed local differential transmissions will also play a role in protecting the system for critical applications.

GNSS/GPS Is Only One Part of an Improved System

Perhaps the most important point to emphasize in summary is that satellite navigation is not the most critical element of the needed system modernization. As important as GNSS/GPS is, it is not an air traffic control system, but only a sensor which a good air traffic control system can use. Better navigation by itself is of limited value if the ATC automation and digital communications are not there to make it useful to improve the ATC system. (For example, it is useful to recall that FAA developed and demonstrated the principles of Automatic Dependent Surveillance in 1972. It went nowhere because there was no ATC automation or data link to make it useful.) While satellites are very important, and are certainly glamorous, the major benefit to users will come from the marriage of satellite navigation with ATC automation and integrated flow management, a real-time digital communications system and the exploitation of the airport capacity technologies which the industry has long pressed.

gnss\obershea.mg

BIBLIOGRAPHY

[1]Lebron, John E. Estimates of Potential Increases in Airport Capacity Through ATC System Improvements in the Airport and Terminal Areas. McLean, Virginia: Prepared for the Federal Aviation Administration by The MITRE Corporation, 1987.

[2]Airports Council International - North America Region. ACI-NA Policy on ICAO FANS, GNSS, ILS/MLS Applications. Washington, DC: ACI-NA, June 1993.

[3]Airports Council International - North America Region. Old Charges and Worries About GNSS Costs and Availability Raised Again. Washington, DC: ACI-NA, April 1993. [A virtually identical document was sent to FAA by RTCA on May 7, 1993.]

NORTH AMERICA ACI
AIRPORTS COUNCIL INTERNATIONAL

June 9, 1993

NEWS RELEASE "The Voice of Airports"

ACI-NA ADOPTS NEW POLICY ON ICAO FANS, GNSS, and ILS/MLS

Recognizing that system integration and better information flow are the keys to a modern aviation technical infrastructure, the Board of Directors of the Airports Council International-North America has established a far-reaching, integrated policy on new ATC technology. The newly-adopted ACI-NA policy recognizes the potent capabilities of satellite navigation and digital communications, but supports the continuation of development of a simple version of a Category 2/3 - capable Microwave Landing System. Elements of the new ACI-NA policy include:

GNSS - The Global Navigation Satellite System is expected to be the primary navigation system enroute and especially in terminal areas, along with the Microwave Landing System (MLS) for Category 2 and 3 final approach and landing guidance. GNSS-based airport surface traffic management would significantly improve airport operations, and is the approach of choice for airport surface operations.

ILS/MLS - ACI-NA supports and urges the early completion of a simpler-than-currently-specified, but Category 2/3-capable Microwave Landing System.

GNSS vs. Terrestrial Radar Sensors - Development of Automatic Dependent Surveillance (ADS) techniques for terminal areas, using GNSS, especially terminal areas where VHF communications is difficult and in those where radar can not be justified, is supported for the future.

The Limits of Automation and Electronic System Services on the Airport Surface -Airports expect to provide visual services for taxiing, and do not anticipate aircraft operating on the airport surface at less than 300' RVR dependent on electronic support services.

(more)

1220 19th STREET, N.W
SUITE 200
WASHINGTON D.C. 20036
(202) 293-8500
(202) 331-1362 (FAX)

page 2 of 2

June 9, 1993

Operational Opportunities - Early implementation of the ICAO Required Navigation Performance concept is recommended, so as to permit evolution from the rigid approach and landing categories and obstacle clearance criteria, to performance-capability-related minimums of the aircraft themselves and their crews.

System Integration/Digital Communications Standards - Development of terminal and on-airport automation systems should proceed, fully integrated and harmonized with more capable air traffic management and flow management techniques. World standard, broadly-applicable digital (data link) communication, fully applicable to satellite and terrestrial communications, is crucial.

ACI-NA noted that it is likely that the GNSS accuracy needed for Category 2/3 operations is achievable...However, the very high availability and integrity required...may require extensive and expensive precautions and redundancy, especially in the aircraft. Even if it makes sense to try to measure a few feet (above the runway concrete) by measuring range to a half-dozen satellites 11,000 miles away, the integrity requirements may not be practical or cost-effective in some types of aircraft, thus continuing to justify pursuit of a simple ground-based landing system.

With respect to MLS itself, ACI-NA believes perhaps the most serious current problem is that the technology, and FAA's and the industry's perception of the need for MLS have changed drastically since the [most recent] MLS procurement request was prepared. The appearance of GNSS satellite navigation with truly astounding capability will supplant some of the features that, in the 1960's and 70's, MLS was intended to provide...Buying MLS now with capabilities no longer needed is not prudent. It is necessary to seek a way to buy the right product without starting over again.

*The **Airports Council International-North America (ACI-NA)** is the **"Voice of Airports"** representing local, regional and state governing bodies that own and operate commercial airports in the United States, Canada and Bermuda; ACI-NA Member airports enplane more than 90 percent of the domestic and virtually all the international airline passenger and cargo traffic in North America. ACI-NA also encompasses Associates representing a wide variety of businesses that provide products and services to the air transportation industry.*

###

Contact: Victoria E. Pannell
Director, Public Affairs

1220 19th STREET, N.W.
SUITE 200
WASHINGTON, D.C. 20036

NORTH AMERICA ACI
AIRPORTS COUNCIL INTERNATIONAL

ACI-NA Policy on ICAO FANS, GNSS, ILS/MLS Applications

Newly-available communications and data processing technologies, and the widely hailed ICAO FANS concept, represent a fine arsenal of enabling technology which, when implemented intelligently by many states and administrations, can make possible major, even revolutionary, aviation system improvements.

System integration and better information flow are the keys to a modern aviation technical infrastructure. The Airports Council International-North America therefore establishes the following integrated policy:

GNSS - **The Global Navigation Satellite System is expected to be the primary navigation system enroute and especially in terminal areas, along with the Microwave Landing System (MLS) for Category 2 and 3 final approach and landing guidance.**

> GNSS alone is expected to serve all navigation needs for many aviation system users. Differentially-augmented GNSS is likely to support operations to at least Category 1 - equivalent minima.

ILS/MLS - **ACI-NA supports and urges the early completion of a simpler-than-currently-specified, but Category 2/3-capable MLS. MLS may now be designed to provide its service in a ±12 degree azimuth front coverage sector, and will no longer require Precision DME.**

> While ILS is likely to have very limited remaining life, airports consider that it is too soon to abandon further ILS procurement. Plans for procurement of a limited number of ILS ground facilities should proceed until the full GNSS service is available, the GNSS capability of providing precision approach and landing guidance fully proven, and the implementation of GNSS airborne equipment well along to universal equipage.

GNSS for Airport Surface Operations - **GNSS-based airport surface traffic management would significantly improve airport operations, and is the approach of choice for airport surface operations.**

> Airport surface surveillance, navigation, guidance and control systems can be implemented in steps.
>
> GNSS position determination accuracy could increase runway capacity in bad weather at airports that have converging or parallel runways where spacing does not permit parallel approaches with current navigation aids.
>
> GNSS could provide precise navigation guidance for drivers of snow-removal equipment to accurately locate the boundaries of taxiways and runways. It is also expected to provide valuable navigation and location services to drivers of emergency vehicles and probably others.
>
> Differential GNSS/Automatic Dependent Surveillance may be capable of providing the data source for separation assurance functions now provided by precision runway monitor (PRM) systems.

GNSS vs. Terrestrial Radar Sensors - Development of Automatic Dependent Surveillance (ADS) techniques for terminal areas, using GNSS, especially terminal areas where VHF communications is difficult and in those where radar can not be justified, is supported for the future.

The need for terminal area weather information, winds aloft on the approach paths and in their vicinity, microburst detection, wake vortex detection, and possibly precision runway monitoring and backup airport surface detection radar will continue to require terrestrially-based independent sensor capability. ACI-NA recommends that administrations aggressively pursue rapid prototype development, and include early emphasis on life cycle costing and issues of equipment complexity vs. capability, in order to establish cost feasibility.

The Limits of Automation and Electronic System Services on the Airport Surface - Airports expect to provide visual services for taxiing, and do not anticipate aircraft operating on the airport surface at less than 300' RVR, dependent on electronic support services.

While ATC surveillance capability and general position orientation (such as may be provided by enhanced GNSS or synthetic vision) would be desirable to near-zero-visibility conditions, ACI-NA believes that there is no need to provide for fully automatic or electronically supported operations in less than 300' RVR conditions.

Operational Opportunities - Early implementation of the ICAO Required Navigation Performance concept is recommended, so as to permit evolution from the rigid approach and landing categories and obstacle clearance criteria, to performance-capability-related minimums of the aircraft themselves and their crews.

The evolving capabilities of GNSS and communications are likely to permit changing the way that operating minima are established. Designations such as Instrument Landing System (ILS) Performance Category I, II or III may no longer be applicable, and minima may be more appropriately established based on required performance of on-board navigation equipment.

System Integration/Digital Communications Standards - Development of terminal and on-airport automation systems should proceed, fully integrated and harmonized with more capable air traffic management and flow management techniques. World standard, broadly-applicable digital (data link) communication, fully applicable to satellite and terrestrial communications, is crucial.

The new capabilities offered by GNSS and ADS increasingly intertwine position-fixing/navigation with the communications process and mandate special attention to the integrity needed to maintain and enhance the safety of the whole system. The airport surface is likely to impose the most serious digital communications requirements.

Because a series of digital communications needs will have to be satisfied, for differential GNSS, for airport lighting and signalling controls, for ADS communications, etc., a major effort is required to assure that the communications needs are dealt with on a system basis, and that a harmonized communications system structure and standards are developed in a timely manner. Airports urge government to concentrate early to develop necessary standards/agreements on digital communications standards for differential GNSS transmissions and airport lighting/signalling controls.

Elements of the ICAO Future Air Navigation System (FANS) concept are of importance to airports and warrant early implementation. They are the following:

1. Improved navigation, GNSS
2. Application of technologies to achieve optimum airport capacity.
3. Early implementation of the Required Navigation Performance concept (RNP) to permit navigation requirements to be stated in terms of required performance rather than specific hardware systems.
4. Terminal and on-airport automation systems, fully integrated and harmonized with more capable air traffic management and flow management techniques.
5. Digital (data link) communication, fully applicable to satellite and terrestrial communications.
6. Airport surface surveillance, navigation, guidance and control systems developed in such a way that new required equipment in aircraft can be avoided.

Adopted
June 4, 1993
Savannah, GA

Background and Policy Rationale

In the formation of the ICAO Future Air Navigation Systems Committee (FANS), a body formed some years ago in the wake of failure of a multi-nation Aerosat North Atlantic satellite effort, a number of states, including the U.S., realized that technology was marching rapidly and it was necessary for states and the International Civil Aviation Organization (ICAO) to be masters of the technologies, rather than followers.

Early in its work, FANS made the crucial and politically difficult decision to be candid about the present state of the aviation technical support system. They said, and it is still true today:

> "In large parts of the world, the plans for communication, navigation, and surveillance systems have proven to be very difficult to implement and operate in a consistent manner....The fact that services are less than adequate in many parts of the world results not only from lack of financing, but in many instances also from lack of trained technical personnel...."
>
> "There appears to be little likelihood that the present air navigation situation will improve within the near future unless new approaches are adopted."

The new future system concept may be able to overcome a number of these problems **if** state administrations move out with energy to use the ideas and technologies becoming available. The new concept requires a high level of international cooperation to succeed. Because efficient air traffic management demands transparent boundaries, political problems and xenophobia must be faced and overcome.

ICAO can take pride in the fact that the FANS concept can serve both very high traffic areas and sparsely populated low activity traffic areas as well. The concept permits improvements in airport and terminal area technology to meet the needs of very busy and more lightly used airports without putting either class at disadvantage.

The FANS Concept

The elements of what has come to be called the FANS concept, accepted by the world through ICAO, are:

1. Satellite technology is the only viable way to overcome the shortcomings of the present system and fulfill the requirements of the future. To that end FANS developed a satellite communications system structure and architecture which can be expected to find wide application in providing data link and voice services, probably first over oceans and undeveloped land areas, for ATC and other safety communications, as well as some non-safety communications. The agreed architecture will permit several suppliers of satellite services to provide compatible and competitive services.

2. For navigation, a Global Navigation Satellite System (GNSS), (made up initially of elements of the U.S. GPS and the Russian [CIS] GLONASS, but architecturally open to other satellite elements) which can provide highly accurate navigation service to anywhere on the face of the globe from the surface to very high altitudes, accurate enough to provide the data for non-precision approaches, and probably at least Category 1 equivalent to any runway end anywhere, without need for ground equipment. GNSS and the Microwave Landing System will be the only navigation systems required

in the future system, retiring the many systems currently in use and complicating aircraft installations.

3. A service called Automatic Dependent Surveillance (ADS) by which aircraft navigation position is automatically transmitted via satellites or other means to ground ATC facilities to create a surveillance capability something like radar (pseudo-radar). This capability will have major impact over oceans and land areas where radar can not be provided, and could make oceans very much like domestic airspace. It will provide a radar-like service in many enroute and terminal areas of the world where radar can't be justified, without the need for complex ground equipment.

4. A concept called Required Navigation Performance capability (RNP) by which there is no longer a need for Administrations (or ICAO) to specify the use of particular navigation devices, but to simply call for given, clearly spelled levels of performance capability in different airspace areas.

5. FANS recognized the important airport capacity problem, and that technologies to permit multiple arrival/departure streams, safe reduction of separation standards laterally and longitudinally, reduction of the impact of wake vortices, independent IMC operations to multiple runway configurations, were under development and being implemented in a number of states .

6. The need for development of terminal and on-airport automation systems, fully integrated and harmonized with more capable air traffic management and flow management techniques was recognized. World standard, broadly applicable digital (data link) communication, fully applicable to satellite and terrestrial communications was seen as an essential ingredient.

7. Recognized to be of great importance, and emphasized especially in the FANS Phase II follow-on work, is a fully harmonized Air Traffic Management system which uses automation aids and services to help create seamless airspace boundaries and permits user-preferred routes in which the ATM system and the aircraft, by appropriate exchange of digital information, can take advantage of the capabilities of aircraft flight management systems.

That's really all. FANS recognized that one of the major keys to success was, and is, agreement on a unified digital communications system (data link) to provide the easy efficient information flow which is the key to ATC improvement. It did not solve that problem, but recommended an ICAO Panel, now slowly at work, to deal with it. In the U.S. FAA has turned to RTCA to help.

FANS recognized that the glue to hold the new technologies together and to create a better system is vastly improved computer and data processing capability to help achieve meaningful, acceptable automation aids, but it left the task to the states, urging states to work in harmony.

In the time since the FANS concepts were formulated and then ratified by the ICAO world body, R&D and experiments/demonstrations have made a number of things clear:

Widely Accepted Capabilities of GNSS

The following are excerpts from the widely-accepted September 1992 RTCA GNSS Task Force Report:

> 1. The GNSS-based system should provide, as a minimum, en route, oceanic, terminal and non-precision approach navigation service with an accuracy of 100 meters.

> Operations using GNSS alone for en route, terminal and "non precision" approach navigation are expected to serve the great percentage of general aviation needs and many of the needs of all aviation users. GNSS will provide for lower operating minima on non-precision approaches at airports that currently have limited navigation guidance.Augmentation of the system, both on and off the aircraft, will provide additional capabilities to users requiring them. (See more below)
>
> 2. GNSS-based Automatic Dependent Surveillance (GNSS/ADS) should become an important source of surveillance information, initially in the less-dense traffic locations where secondary surveillance data is difficult to justify.
>
> For airport surface traffic management (aircraft and airport vehicles), augmented GNSS is expected to become the primary surveillance and control data source, backed up by radar where appropriate, with a variety of different application levels depending on airport layout and traffic density. These surveillance applications will require high-integrity two-way data (data link) communications.
>
> 3. As a consequence of high accuracy GNSS position fixing and navigation service, a new approach to the definition of obstacle clearance standards is possible. Similarly, the introduction of GNSS opens the way for a better categorization of landing minima.
>
> 4. The introduction of highly accurate GNSS/ADS should permit a major reduction in minimum aircraft separation standards for operation in oceanic airspace and any airspace currently without high quality surveillance service. GNSS/ADS should provide surveillance of nearby aircraft (in the airspace) and vehicles (on the surface) as input to certain tactical traffic displays for separation functions.
>
> 5. Differential GNSS/ADS may be capable of providing the data source for separation assurance functions now provided by precision runway monitoring. The time standard used in the separation of aircraft at a common point (four-dimensional navigation) should be calculated based on GNSS time.

Other Possible/Probable Capabilities of GNSS and Data Link

FAA has reported that, based on tests/demonstrations, augmented GNSS (with data linked differential GPS transmissions from simple nearby ground stations) will support Category 1 approach and landing operations. The report of a recently completed series of flight tests conducted by FAA with Honeywell, MITRE Corporation, Northwest Airlines and ATA states:

> **"Satellite-based navigation offers the potential to provide all basic Instrument Flight Rules (IFR) capabilities, including oceanic, en route, terminal area, non-precision approach and Category I precision approach capabilities with a common navigation system.** Satellite-based navigation may also provide these capabilities at many locations in the world where conventional navaids are not currently provided nor economically feasible...This could lead to eventual phaseout of existing National Airspace System ground equipment while maintaining or improving existing levels of service."

GNSS Capability for Category 2/3 Operations ?

There is a body of opinion that data quality may be achievable to permit Category 2 and possibly Category 3 autoland operations. **If that becomes fact, it becomes appropriate to question the future need for ground-based landing systems such as ILS or MLS.**

The newly-adopted ACI-NA policy on MLS recognizes that potentially very potent capabilities of satellite navigation and digital communications, but continues to support the early development of Category 2/3-capable, but now simpler MLS than earlier considered.

It is likely that the GNSS accuracy needed for Category 2/3 operations is achievable, especially in the horizontal plane. However, the very high availability and integrity required (e.g. very low failure rate and failure warning within .5 to 1 second after a failure) may require extensive and expensive precautions and redundancy, especially in the aircraft. Even if it makes sense to try to measure a few feet (above the runway concrete) by measuring range to a half-dozen satellites 11,000 miles away, the integrity requirements may not be practical or cost-effective in some types of aircraft, thus continuing to justify pursuit of a simple ground-based landing system.

Early major modification will be needed for all ILS receivers in any case because of interference from the about-to-be-allowed higher-powered FM broadcast stations. The modifications which would be required for all ILS receivers (still based on a technology devised before World War II) are probably not economically sensible in the light of the far more capable, and now simpler MLS.

Because the FM broadcast interference problem affects primarily the localizer portion of ILS, there have been suggestions that, instead of moving to MLS, GNSS lateral information might become adequate for Category 2/3 operations and that the ILS glide slope might be retained to help out the weaker vertical GNSS signals. While this is a possibility, the 1930's ILS glide slope depends on the frequently uneven terrain in front of the antenna to create its signal, is frequently limited in coverage, and is fundamentally less robust than the MLS which should provide guidance routinely to a few feet above the runway.

ACI-NA in July, 1992 commented to FAA on the continuing problems of MLS procurement, as follows:

> "Perhaps the most serious current problem is that the technology, and FAA's and the industry's perception of the need for MLS have changed drastically since the MLS procurement request was prepared. The appearance of GNSS satellite navigation with truly astounding capability will supplant some of the features for which, in the 1960's and 70's, MLS was intended to provide. A recent flight test report published by FAA shows that FAA expects GNSS to supplant special landing aids at least for Category 1 operations. GNSS will provide high quality broad-sector coverage for flexible approaches, missed approach guidance and other capabilities, which are no longer needed from MLS.
>
> Buying MLS now with capabilities no longer needed is not prudent. It is necessary to seek a way to buy the right product without starting over again.
>
> We recommend that FAA establish the valid requirements for the now far-simpler MLS required to meet the final approach and landing guidance requirements as they are understood to be as of perhaps 1996, when GNSS will be far along into implementation and use. Adapting the specification to current needs (reduced-width front sector, elimination of back course coverage and elimination of Precision DME) is crucial if the government is to get its money's worth.

> **Rather than calling for compliance with dozens of pounds of specifications, [we recommend that FAA] negotiate with the contractors and establish performance requirements including technical signal performance, guaranteed MTBF and MTBR and other specifications which demonstrably contribute to meeting FAA's needs. The MLS development task will inevitably be stifled by a too-rigid process in which every detail is specified.**

Automatic Dependent Surveillance (ADS) with GNSS and Data Link - Replacement for Ground-based Surveillance?

There is a body of opinion that postulates that GNSS with digital communications to create Automatic Dependent Surveillance (ADS) will eventually replace ground primary radar and perhaps secondary surveillance radar as well. **If that were to occur, the need for ground-based ATC surveillance systems would disappear.**

With respect to the future need for primary radar, it may be possible to phase out primary radar for **enroute** operations, in favor of Secondary Surveillance Radar, and/or GNSS-driven Automatic Dependent Surveillance (ADS). The transition to GNSS ADS, if it becomes appropriate, will depend on the proof of integrity of GNSS ADS and the level of carriage of GNSS and digital communications capability of aircraft using the enroute system. The situation in **terminal** operations is different from enroute. Multi-function phased array sensors are likely to be attractive for FAA services in the future. This technology offers high promise of providing a number of critical FAA services - meteorological (winds aloft, microbursts, weather detection, etc.) wake vortex detection and monitoring in real time, and backup surveillance, even when GNSS ADS is available - within a single, integrated and potentially affordable sensor.

The close proximity of aircraft to each other may indicate the continued use of surveillance radar - albeit secondary surveillance radar if universal, operating transponder carriage can be assumed and any residual TCA intruder issues resolved - for a longer period than in the enroute case.

Consideration of the future of ATC surveillance radar in the terminal area (for example vis a vis GNSS ADS) is a different matter because of 1) the inherently dependent character of ADS and 2) other needs for terminal area surveillance data. The need for terminal area weather, winds aloft on the approach paths and in their vicinity, microburst detection, wake vortex detection, and possibly precision runway monitoring will continue to require terrestrially based independent sensor capability, regardless of the promise of GNSS ADS. If these needed capabilities can be provided from a single system which also can provide residual ATC surveillance, economies may be achievable, and the difficult system integration and transition task for terminal area functions can be simplified.

The recent development of highly capable multi-function sensor technology, made possible in large part by reduced-cost phased-array elements, may perform the above functions efficiently, and is likely to provide primary and secondary radar surveillance at little marginal cost.

The technology to create such multi-function sensor equipment appears far along and deserves support. FAA should aggressively pursue rapid prototype development (including sensor fusion, field testing, and demonstration) of multi-function radars for the task above. This development should include early emphasis on life cycle costing in order to establish cost feasibility, and should address issues of equipment complexity vs. capability.

Appropriate emphasis must be placed on redundancy and reliability, reflecting both the functional criticality and the inherent reliability/integrity characteristics of the technology.

Standards and Uniformity for Digital Communications and Data Links

It has been understood for many years by observers of the ATC system that rapid, efficient and inexpensive information flow is crucial to improvements in the airspace/airport/ATC system. Automated digital communications - data link - is the key, but lack of agreement on standards or even uniformity of such systems has prevented their implementation in the ATC system, and thus also real ATC automation, for many years.

The matter becomes especially important to airports for three reasons: Lighting control systems are increasingly being driven by software for which signalling standards are needed, not only because uniformity would save money for airports, but because in the future there must be a tighter connection between lighting controlled by the airport and signalling controls which may be operated by FAA. Second, GNSS with Automatic Dependent Surveillance used on the airport surface requires agreement on a signalling standard, preferably one the same as or similar to that being used in the airspace. Third, the use of differential GNSS requires a high-integrity, but simple and inexpensive data link to aircraft using GNSS for approach and landing, to aircraft and vehicles requiring high accuracy position on the airport surface.

Add to this mixture the data link systems needed to serve satellite communications, the ATC Beacon UHF Mode S data link system, the airlines' ARINC VHF ACARS or its AvPak enhancement, and a Swedish VHF time-division multiple-access system being evaluated at O'Hare, and the need for a concentrated effort to find some level of agreement and standardization becomes obvious.

Like virtually all users, ACI-NA has urged FAA to move rapidly to establish needed standards, especially for the GNSS differential transmissions. RTCA, at FAA's request, has formed a special Task Force (Task Force 2), similar to the one RTCA just completed successfully on GNSS, to help sort out this tough problem and try to reach agreements. ACI-NA and airports are involved to assure airport interests are considered. The ACI-NA Technical Committee has asked RTCA to look at the lighting control system needs to recommend the level of compatibility/uniformity needed for such systems with other, ATC data link control systems.

STATEMENT OF MARTIN (Marty) POZESKY, FAA ASSOCIATE ADMINISTRATOR, SYSTEM ENGINEERING AND DEVELOPMENT, BEFORE THE COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION, SUBCOMMITTEE ON AVIATION, JULY 28, 1993

Mr. Chairman and Members of the Committee -- Thank you for this opportunity to appear before you to discuss what is clearly the most significant air navigation program the FAA has undertaken in recent times. I am joined here today by my colleague, Mr. Anthony Broderick, the FAA Associate Administrator for Regulation and Certification, who is well known to you.

The satellite technology used in the Global Positioning System has incredibly far reaching potential for the future of aviation. Two years ago, a satellite-based navigation system for civil aviation was still only hope. Today, we are well on our way to having a single navigation system that can handle all phases of flight all over the world with unprecedented accuracy. GPS, combined with advanced telecommunications and higher levels of automation, offers unlimited opportunities for improvement in aviation safety, capacity, and efficiency.

Major operational benefits are expected to accrue from use of this combination of GPS, automation, and data link. These include fuel savings, reduced flight time, reduced avionics requirements, more efficient flight paths, and reduced delays --all made possible by procedures that flow from more accurate area navigation information and improved surveillance. These benefits will be realized first in the oceanic airspace where this technology will be used to provide optimized flight paths to greater numbers of aircraft. Using a combination of GPS position information relayed back to the ground through a commercial satellite communication link (such as currently provided by the INMARSAT system) this technology combination will provide a pseudo-radar surveillance capability over the ocean where no such capability exists today. Thus, more aircraft can safely make use of the "best-wind" tracks across the ocean saving significant fuel and operating cost.

General Aviation may even enjoy greater benefits from this capability. Consider the approach and landing capability alone. The real possibility exists to provide both precision and non-precision approach capability to virtually every airport in the country as well as the world through this combination of systems. Both general aviation and the major commercial carriers will enjoy far greater operational flexibility by having available (at minimal cost) a huge number of additional instrument approaches without the need for very expensive ground investments.

The FAA is a strong advocate of GPS, as we hope the Committee will be at the conclusion of this hearing. What is also very exciting is the fact that the FAA has played a leadership role in the application of this exciting new technology to aviation. Working cooperatively with the Department of Defense and with system users, we have progressed on the technological, operational and institutional fronts simultaneously. I believe that by any reasonable measure of achievement, we have progressed at "lightning speed" thus far.

While our enthusiasm will be clearly evident in the course of these hearings, please be assured that we are very mindful of the safety implications of the system and are taking all the necessary steps to insure that this future system will be at least as safe and reliable as the systems that have served us so well over the past decades. What we are talking about is enormously more capability at equivalent (or even enhanced) levels of safety and integrity through the proper mixture of satellite technology, separate integrity and monitoring systems data links, cockpit, and ATC automation. Focus again on the combination, because that is what is needed -- GPS for precision navigation, data link for error free computer-to-computer communication, ATC as well as flight automation to develop the optimum integration of traffic and the best combination of capabilities.

Until now, air navigation has made use of a variety of radio-navigation systems which provide reasonably precise and reliable position information. Systems such as VOR/DME (Very-High Frequency Omni-Directional Range/Distance Measuring Equipment), Loran-C (for long-range navigation), Omega and ILS (Instrument Landing System) have provided excellent, wide-ranging navigation capabilities; but for some phases of flight all are limited in either coverage or accuracy, or both. Therefore, users must carry several types of receivers to obtain navigation service for all phases of flight.

Satellite technology, and specifically GPS, will provide continuous, reliable, accurate position information for all phases of flight to users worldwide. By the end of this year, DOD will declare Initial Operational Capability for GPS. However, even before this formal declaration, we have begun to use GPS in domestic and oceanic airspace. The FAA has approved use of GPS as a supplemental aid for enroute and terminal navigation and for non-precision approaches. We are conducting tests to allow the private use of GPS for precision landings and at least one airline is intending to make use of that capability this year or early next. We have already issued our Technical Standard Order for supplemental use of GPS in the national airspace system and have issued procedures for use of GPS as a non-precision approach landing aid. In fact, I must tell you that this is the first time that I can remember that we have had procedures in place for new technology before the certified avionics equipment became available.

The Defense Department pioneered this system 20 years ago and had the foresight in their original concept to include a civil mode. Without that visionary foresight on the part of a few individuals, we might not have this capability today. Cooperation between the DOD and FAA on this system has been outstanding. The FAA has been working closely with the user and supplier community, as well as with the international community through ICAO, to gain the full and early benefits of this vastly improved technology for civil air navigation. For example, about 18 months ago, the FAA asked RTCA -- a preeminent aviation organization -- to be the forum for the development of a US aviation industry-wide consensus on moving toward satellite navigation. That landmark effort was completed in September 1992 resulting in broad community support for early transition to GPS and satellite technology.

On the international scene, the FAA has been working through ICAO to foster the early introduction of satellite technologies to world-wide aviation applications. Last year, in a coordinated effort, the US Government formally offered the Standard Positioning Services (or "civil" mode) of GPS to ICAO for aviation use throughout the world without direct user costs. It was envisioned to use this as a transition step to enable early movement toward satellite technology. We are moving, the world is moving, and it is exciting to see the momentum build in support of this transition.

There are still a number of legitimate policy and technical issues to be addressed as we begin to rely on this new technology and make plans to phase-out the older systems. On this front, we are very sensitive to the need for an overall government strategy to address all of these issues -- not just an FAA strategy, but a US government strategy. This include fine-tuning of a set of issues ranging from national security protection of GPS to system accuracy, and operational integrity. These questions, however, will not prevent us from beginning operational use -- and learning from our experience -- as we continue to develop the means to rely solely on GPS for air navigation. We are addressing all of these issues in our research & development, testing, and operational activities.

Most importantly, a comprehensive set of policies and strategies to provide for civilian use of this system are being developed under the leadership of a working group already chartered by Secretary of Transportation Pena and Secretary of Defense Aspin. This group got started shortly after the new Administration took office and is expected to complete its initial work in November of this year. The goal, simply stated, is to insure the long term availability of GPS as an asset to all modes of transportation -- not just aviation.

Let me step back for a few minutes and describe a little about the GPS system. The GPS satellites have been placed in orbit by DOD 11,000 miles above the Earth and emit continuous, identical radio signals. A simple receiver measures the distance from at least four satellites by calculating the time it takes the signal to arrive and thus pinpoints its own location. The satellites provide complete worldwide coverage at both low and high altitudes. As it becomes more refined, it appears as if GPS can substitute for most other aviation navigation systems.

The Standard Positioning Service is available to any GPS user worldwide with a commercial receiver at no direct charge to the user. It is specified to be accurate to within 100 meters, horizontally, and 140 meters, vertically 95% of the time. The Precise Positioning Service (PPS) is more accurate and will be limited to military and specifically authorized civil users.

The Basic SPS signal, while providing a significant improvement over existing methods of navigation, needs augmentation to meet the full range of anticipated aviation applications. As it currently exists, GPS can be used as a supplemental system for oceanic, domestic en route, terminal and non-precision approach navigation. The next step will be to use GPS for Cat I precision approaches. To meet these requirements, we are developing a feature called "Differential GPS."

Differential GPS will enhance the accuracy of GPS for all users within coverage of this differential capability. Simply stated, the system will correct for known errors in the satellite signals and transmit error correction messages directly to the aircraft GPS receivers. This will effectively remove most of the errors in derived GPS position within coverage of this differential system. GPS, with this differential capability, should allow precision landings at a very modest cost at virtually every runway end in the world. In addition, this improved accuracy would allow GPS to be used to navigate around the surface of an airport in low visibility conditions -- thus a safety enhance to provide further protection against runway incursions. Even an improved GPS based TCAS (what we have begun to call TCAS IV) is possible.

There are two types of Differential GPS: Local-area and wide-area. Local areas systems will make use of simple data-link transmitters located, say, at an airport. These are not much more complicated than a normal VHF radio and are available now. Because of their low cost and simple design, they are reasonable affordable and can be provided by local operators and communities to meet their needs. Local differential systems will have a coverage radius of about 20-25 miles and probably will provide a little more accuracy than the wide-area system.

The wide-area system is a more elaborate system and will involve the transmission of correction signals from geo-stationary satellites that will cover large land areas such as the whole of the U.S. It will require a fully integrated network of ground monitors and a few broadcast satellites to transmit the corrections. Our current belief is that wide-area DGPS will use 20 ground-based monitors evenly spaced across the United States. The ground-based monitors will effectively correct the satellite information. We are doing the development work now and have recently completed some testing of this capability at Technical Center in Atlantic City.

Now that I've described what GPS is and what it can do, how can we make full use of those satellites already in place? We believe that full utilization will require ongoing progress in three areas simultaneously: technical, operational, institutional. The FAA is actively engaged in each of these areas and has made significant inroads.

Technical

Several major technical projects are underway in the FAA R&D Service to support a rapid implementation of GPS technology. First, the wide-area differential network is being designed to augment the basic satellite constellation providing integrity, more satellite availability and better accuracy. On-line testing with our wide area test bed facility at the FAA Technical Center is ongoing, with a target to provide accuracy supporting all phases of flight down to Category I precision approaches.

Local-area differential research is focusing on early Category I precision approach capability for private users. Current activities in this area are being conducted with regional air carriers, which will be the first to benefit from this technology.

Research is underway to further improve the local-area concept by demonstrating feasibility of this technology to support

Category II/III precision approaches. This feasibility demonstration should be complete by 1995. In coordination with industry and RTCA, we are also working on avionics and ground system specification development to ensure that the systems are interoperable and satisfy user requirements.

Advanced R&D projects are continuing to investigate the potential of GPS to support advanced navigation and other functions such as weather prediction, airport surveillance, height monitoring over the oceans, GPS-based attitude information, a GPS-based TCAS, to name only a few.

We are working on several bilateral agreements to undertake R&D that would enhance GPS acceptance abroad. International programs covering pilot/controller procedure development, avionics specifications and advanced GPS applications are being enthusiastically pursued by the FAA's Satellite Program Office.

Operational

Our work has been just as aggressive to move GPS along operationally. FAA has approved the supplemental use of GPS for all phases of flight, including non-precision approaches to airports. With this approval, GPS can be used to fly existing VOR, NDB and RNAV approaches. In tests undertaken in conjunction with Transport Canada, FAA has tested and approved instrument approach overlay procedures that will permit non-precision approaches at about 2500 airports in the U.S. Further, last December, after working closely with industry manufacturers, FAA issued certification criteria for GPS receivers. These are expected to be available from U.S. manufacturers this Fall.

These and similar operational procedures in support of early satellite navigation implementation were developed by the FAA The actual development of operational procedures and standards, however, is a primary function of the FAA Satellite Operation Implementation Team, known as SOIT. SOIT is a prime example of how FAA has met the challenges of timely satellite navigation development in aggressive, new and creative ways. SOIT was formed in 1991 to establish the technical, operational, and certification requirements and procedures necessary to authorize GPS use as soon as incremental improvements in various capabilities become able to satisfy IFR requirements for a particular phase of flight. Because of SOIT's work, certain aircraft were authorized as early as last year to use GPS information, as long as traditional navaids were available to cross check the GPS readings. SOIT's aggressive pursuit of early operational implementation resulted in the development of a Technical Service Order (TSO) that redefines the minimum operating performance standards to permit navigation, thus increasing GPS availability.

Institutional

On this institutional side, I have already mentioned the DOD/DOT joint task force which is underway to ensure the long-term utility of GPS as a national asset. The Task Force will examine issues such as joint management, operation and funding. It will be the task force's job to determine the level and types of long-term civil augmentation that can best be implemented. The task force is addressing legal, liability and national security concerns, with its initial recommendations expected around November.

Ultimately, satellite navigation is a worldwide venture. The FAA, together with ICAO and other members of the civil aviation community have recognized that the primary stand-alone navigation system in the 21st century will be provided by a Global Navigation Satellite System (GNSS) of which GPS will be a part -- maybe even a major part. The FAA has offered the use of GPS for international civil aviation as a part of the ICAO Global Navigation Satellite System (GNSS) -- the international term for the future satellite navigation system. It is important to understand that there is a difference between GPS and GNSS, it is already becoming clear that the world will use GPS as a first step, if you will, toward satellite navigation.

This is a very exciting time. We are pursuing this technology as rapidly as possible but we are mindful of the safety implications of the system and take all the necessary steps to insure that the system of the future will be as safe and reliable as the systems that have served us so will over the past decades. What we are talking about is enormously more capability without sacrifice of system integrity, reliability, or safety.

That completes my prepared statement, Mr. Chairman. We would be pleased to respond to any questions you and the other Members of the Committee may have at this time.

RTCA

RTCA, Inc.
1140 Connecticut Avenue, N. W., Suite 1020
Washington, D. C. 20036

Telephone 202-833-9339
Facsimile 202-833-9434
Telex 2407254 RTCA UQ

STATEMENT OF

David S. Watrous, President

RTCA, Inc.

Before the

United States House of Representatives

Public Works and Transportation Committee

Subcommittee on Aviation

July 28, 1993

Future Uses of Satellite Technology in Aviation

"Requirements and Technical Concepts for Aviation"

We are on the threshold of the most significant change to occur within civil aviation since the introduction of radio and radio navigation over 50 years ago. This change is made possible by new technology -- fast, powerful airborne and ground-based computers, a satellite system that can provide the air transportation system with aircraft position to an accuracy of 300 feet or better and universal time to an accuracy of less than one one-millionth of a second, plus a different satellite system that can provide accurate, dependable and essentially instantaneous voice and high-volume data communications among appropriately equipped airborne and ground-based elements of the air transportation system.

My purpose today is to acquaint you with some of the opportunities that this technology is making available to the community and the role that RTCA is playing in transforming opportunity into operational implementation.

To put this change in perspective, some background information is essential.

The communication, navigation and surveillance capability upon which today's air traffic control system is based represents 1940's technology and the concepts that that technology could support.

RTCA, then known as the Radio Technical Commission for Aeronautics, helped lay the foundation for today's all-weather air traffic navigation and control system using those concepts and technology. In fact, we received the Collier Trophy in 1948 from President Truman for this accomplishment. During the early years of implementation, the electronics technology installed in aircraft and on the ground were well-matched, and procedures were in place to capitalize on this technology. In a word, the "system" was well-balanced.

In the intervening years, much has been done to incrementally improve the system — radar has been added to improve surveillance; more frequencies have been added to accommodate the increasing need for improved communications; and many incremental improvements have been made in the performance characteristics of civil aviation electronics. During this process, technology has been introduced into airborne and ground segments at different rates, and the balance among airplanes, airports and air traffic procedures has eroded.

The civil aviation community needs a new, more capable system concept embracing airplanes, airports and procedures to meet the pressing need for increased system capacity, efficiency and safety. Fortunately, new technology is now available to provide the sorely needed capability. GNSS/GPS can provide the universally available precise position and time information that is needed to establish the location of all aircraft at any instant. Satellite-based communications can provide the capability for aircraft and the air traffic management system to maintain instantaneous, high-volume, error-free communications, even over the remote oceanic and land-based portions of the earth that are not served by more traditional communications. Airborne flight management computers and ground-based air traffic management computers, using digital communications, can exploit this information by automating and expediting the exchange of real-time information, "crunching" numbers and providing air crew members and air traffic managers with the information they need to make decisions faster and with better information. Equally important, because some of this improved capability is already available in the newest aircraft that are currently in service, some of the operational and economic benefits made possible by new technology can be implemented now, through the use of new policies and procedures, without requiring major new investments. The result will be enhanced capacity, efficiency and safety for the air transportation system.

Decision makers from both the public and private sectors of the aviation community recognize the need for change and the opportunity provided through the implementation of the new technology. Action is underway, first to define a new concept, then to make the requisite investment in policies, procedures and equipment that will implement the new capability using an evolutionary approach at the earliest practical time. At issue is not "whether" to change but rather "when" and "how" to change. There is good community cooperation in this effort with the private-sector users taking the much more aggressive role in urging improvements in 1993 or 1994 rather than closer to the turn of the century.

With that as prologue, now I'd like to focus on initiatives to change the system and the role that RTCA is playing in this very important endeavor.

In late 1991, the FAA Administrator wrote to RTCA that "the recent ICAO Tenth Air Navigation Conference resulted in international agreement supporting the adoption of the Future Air Navigation System/Global Navigation Satellite System (GNSS) as a key element of the future Air Traffic Management (ATM) system. Within the U.S., the FAA and virtually all of the aviation community strongly support the rapid movement toward the implementation of GNSS...."

"Many times in its past, RTCA has played a role as a technical forum where the entire aviation community can come together and examine broad system concepts, as well as the more detailed technical requirements to implement these concepts.... We believe that RTCA is well positioned to develop community consensus addressing the general subject of implementation of GNSS in the United States. Specifically, we request that RTCA establish a senior-level activity...to examine the various applications of GNSS...and develop a series of basic technical system requirements to achieve the various desired capabilities...."

As you may know, RTCA is a private, non-profit corporation that addresses requirements and technical concepts for aviation. The organization has served the aviation community for over 50 years by providing a forum where government and industry representatives gather to address aviation issues and to develop recommendations.

RTCA functions as a Federal Advisory Committee and draws on the full spectrum of the community — airline, business and general aviation users, government regulators, airframe manufacturers, avionics and aviation service suppliers — to prepare consensus-based recommendations on the issues. Although our recommendations have no authority in and of their own right, they do represent the community's consensus view and are usually accepted by the FAA as a basis for the Technical Standard Orders that serve as the basis for designing and building new avionics equipment. Our recommendations are also accepted as "de facto" standards for such processes as the testing of avionics equipment and the development of certifiable aviation software. In essence, RTCA provides the means by which users, government and suppliers meet, reach agreement and set in motion the technical evolution of the air transportation system. In addition to the standards for testing and software development, RTCA has also prepared the basis for standards used to certify communication, navigation and surveillance equipment. Currently we are developing recommended standards for satellite-based navigation receivers, satellite communications, the aeronautical application of computers and related technology. Recently we expanded our horizons to take a true "systems" approach to aviation issues, thereby including within our deliberations those considerations dealing with ground systems, airports and their interoperability with aircraft systems.

It is important to note that RTCA provides the FAA and the aviation community a unique service — the proven ability to draw upon the entire aviation community and to develop a broad based consensus on critical aviation issues. The government does not have this capability in house. Several years ago the FAA attempted to accomplish the RTCA function internal to the organization and after a short period rejoined RTCA and again sought RTCA assistance in developing recommended standards and technical guidance documents. Neither can industry, by itself, perform the RTCA service. While a single organization or contractor can prepare recommendations on essentially any topic, the resulting recommendations will not represent the consensus views and opinions of the aviation community and hence will be much more narrow in their perspective and scope. RTCA is indeed unique and provides a capability that is needed by the FAA and could not be easily duplicated.

Financial support for RTCA's activity is principally derived from funding provided by government and industry members.

Given its "consensus-producing" capability and its proven track record, RTCA accepted the Administrator's tasking and immediately set about creating the GNSS Transition and Implementation Strategy Task Force. Emphasis was placed on achieving an early GNSS initial operational capability.

Organization, leadership and broad participation were clearly going to be key elements in the success of the GNSS Task Force. RTCA invited Mr. James Abrahamson, then Executive Vice President and President, Transportation Sector of Hughes Aircraft Company, currently Chairman of Oracle Corporation, to chair the Task Force. Mr. Abrahamson agreed. The objective of the Task Force was to develop aviation community consensus on early implementation of GNSS, and it drew heavily on the work of two ongoing RTCA committees, Special Committee 159, *Minimum Aviation System Performance Standards for Airborne*

Navigation Equipment Using The Global Positioning System (GPS) and Special Committee 169, *Aeronautical Data Link Applications.* The thrust of the Task Force was to focus on user needs and perspectives. The scope of the Task Force effort was very broad — to include initial and transition considerations as well as technical issues.

Due to the magnitude of the issues and a limited time frame, five Task Force Working Groups were formed to address the following specific types of issues:

- Applications and Required Procedures (Working Group 1)
- Technical Requirements and Compromises (Working Group 2)
- Transition Issues (Working Group 3)
- Institutional Issues (Working Group 4)
- Future Directions (Working Group 5)

The Task Force included over 200 volunteers, representing a broad cross-section of the aviation community, and worked approximately nine months in developing its conclusions and recommendations.

In brief, the RTCA Task Force on GNSS Transition and Implementation Strategy concluded that:

- aviation system users need and want the operational benefits that will accrue with the use of GNSS.
- the technology required to achieve a GNSS initial operational capability is available.
- there are no institutional issues that should preclude an early, initial operational capability.
- the transition to GNSS-supported operations should be user-driven and should occur in an evolutionary manner.
- Initiatives to address and resolve issues attendant with longer-term use of GNSS should promptly begin.

GNSS is a here-and-now capability that will provide major operational benefits to all users of the air transportation system. The Task Force strongly recommended implementation of an early initial operational capability and follow-on efforts to quickly resolve longer-term institutional and equipment development issues.

Included as an attachment to this statement is a copy of the *GNSS Transition and Implementation Strategy Task Force Executive Summary.* Copies of the report itself can be made available to support the Committee's deliberations.

On October 13, 1992, RTCA presented the GNSS Task Force Report to the FAA Administrator. The FAA has enthusiastically embraced the report's conclusions and recommendations. The Administrator also took cognizance of our comments regarding the need for a similar effort focused on the subject of digital communications. RTCA was asked to form another Task Force, the purpose of which was to develop consensus recommendations regarding the early implementation of digital communications. That effort is now underway.

The new RTCA Task Force, Transition to Digital Communications, is chaired by Mr. Louis J. Mancini, Vice President, Engineering Inspection and Quality Assurance for Northwest Airlines. We formed three Working Groups to focus on the major aspects of the transition issue:

- Operational Requirements and Applications (Working Group 1)
- Institutional Issues and Transition Strategy (Working Group 2)
- Technology Choices and Opportunities (Working Group 3)

Each Working Group is addressing the following four topic areas from their respective vantage points:

- Air Traffic Management
- Precision/Non-precision Approaches
- Airline Operational Communications and Passenger Services
- Airport Surface Surveillance/Control

The Working Groups are considering all of these areas of concern for the near term (1-3 years; for the median term (3-5 years); and for the long term (5-10 years).

Once again, we are operating as a Federal Advisory Committee. Our deliberations are open to all who have an interest in the subject of civil aviation digital communications. Approximately 100 volunteers have thus far participated in the consensus-building process.

The Requirements Working Group is making progress in identifying a variety of air traffic management, precision approach to landing, airline communications passenger services and airport operations functions that will benefit from the introduction of digital communications. They are also attempting to quantify the operational benefits that would accrue to those who invested in equipment that makes use of new technology. Implementation of essentially all functions will depend on increased use of ground-based computers, and several will capitalize on the precise time and instantaneous position information that is available through the use of the United States- developed Global Positioning System.

To illustrate the later point, information that has become available since completion of the GNSS Task Force report was completed suggests that GPS, with augmentation from the use of differential GPS equipment, can be used to establish the real-time position of an aircraft with an accuracy of 2 to 5 meters (6 to 16 feet) and possibly through the use of more sophisticated computer processing techniques, to an accuracy of several inches! Much more testing and analysis is yet required, but there is strong preliminary evidence to suggest that GPS can support precision approaches to better than Category I minimums. RTCA's new Task Force expects to have a recommendation for the data link associated with use of the differential GPS technology within a few weeks.

In a similar manner, the Technology Working Group in assessing the status of available technology and preparing cost and schedule estimates for introducing various manifestations of computers, satellite-based navigation and satellite-based communications.

The Institutional Group is addressing both domestic and international policy and procedural issues, preparing appropriate recommendations and investigating alternative implementation strategies and schedules.

The Task Force, in plenary session, will reach consensus regarding all digital communication task force conclusions and recommendations late this calendar year.

These are exciting times. The technology needed to resolve long standing operational issues is now at hand. The civil aviation community needs to decide what it wants to do, agree on how and when to proceed — then IMPLEMENT!

The recommendations from the GNSS Task Force and the Digital Communications Task Force will provide the consensus-based plan; however, there still will be a great deal of work to do. The community will need to think differently about issues and opportunities. We will need an entirely new concept for operating the air transportation system. FAA will need to develop, then implement, new operating policies and procedures and new equipment certification procedures. In fact, new concepts and procedures will be needed to certify and operate the air traffic management system and its many air and ground elements as a "system" — from end to end — including both the airborne equipment and the ground-based equipment with which it will work on a real time interactive basis. These are primarily FAA responsibilities but RTCA and the industry can help.

Similarly, the community will need new performance standards to be used in designing, building and certifying equipment — an RTCA activity.

New electronics incorporating the new technology will be needed — the responsibility of the FAA, airplane users, airport operators and suppliers.

We will need a true government/industry partnership to be successful in implementing the needed change. RTCA not only is well-postured but also has the structure and the experience to achieve that goal. Our initiatives and programs are structured by our Board of Directors, which includes:

Steven J. Brown, Aircraft Owners and Pilots Association
B. Richard Climie, Consultant
Frank J. Colson, Department of Defense Policy Board of Federal Aviation
John J. Fearnsides, Center for Advanced Aviation Systems Development,
  The MITRE Corporation
J. Roger Fleming, Air Transport Association of America
James W. Hardy, Hughes Aircraft Company
Andrew T. Hospodor, Aeronautical Radio, Inc.
John E. O'Brien, Air Line Pilots Association
Richard A. Peal, Boeing Commercial Airplanes
Siegbert B. Poritzky, Airport Council International-North America
Martin T. Pozesky, Federal Aviation Administration - ASD-1
C. Dennis Wright, National Business Aircraft Association
David S. Watrous, RTCA, Inc.

Our volunteers come from the full spectrum of the government and industry segments of aviation.

Technology is available. The process for achieving consensus is in place. The United States can and should lead the aviation community in achieving new levels of capacity, efficiency, and safety.

The question before all of us is not IF, it is HOW and WHEN. Now is the time for action!

##

RTCA

EXECUTIVE SUMMARY

RTCA Task Force Report
on the
Global Navigation Satellite System (GNSS)
Transition and Implementation Strategy

RTCA, Inc.
September 1992

EXECUTIVE SUMMARY

RTCA TASK FORCE REPORT ON THE GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) TRANSITION AND IMPLEMENTATION STRATEGY

September 1992

CONTENTS:

Overview . . . . page 1

Background . . . . page 1

Basic System Description . . . . page 2

Operational Applications and Benefits . . . . page 3

Transition to GNSS . . . . page 4

Institutional Considerations . . . page 7

Technology Considerations . . . page 8

Future GNSS Improvements . . page 9

Task Force Primary Recommendations . . . page 10

RTCA

RTCA, Inc., a non-profit organization whose membership represents a cross-section of the aviation community, operates as a Federal Advisory Committee. Through the use of volunteers, RTCA regularly develops consensus recommendations on major aviation-related communication, navigation and surveillance issues.

Inquiries and comments concerning RTCA and its publications can be addressed to:

RTCA, Inc.
1140 Connecticut Avenue, N.W.
Suite 1020
Washington, D. C. 20036-4001

Telephone: 202-833-9339
Facsimile: 202-833-9434
Easylink: 62805284
Telex: 2407254 RTCA UQ

OVERVIEW

Implementation of the Global Navigation Satellite System (GNSS) represents the greatest opportunity to enhance aviation system capacity, efficiency and safety since the introduction of radios and radio-based navigation more than 50 years ago. Operational use of GNSS offers civil aviation two major opportunities:

- to significantly improve both the accuracy and timeliness with which aircraft position information can be determined everywhere in the world.
- to effect a fundamental change in the concepts used to manage aircraft operations and the procedures attendant therewith.

In brief, the RTCA Task Force on GNSS Transition and Implementation Strategy concluded that:

- aviation system users need and want the operational benefits that will accrue with the use of GNSS.
- the technology required to achieve a GNSS initial operational capability is available.
- there are no institutional issues that should preclude an early, initial operational capability.
- the transition to GNSS-supported operations should be user-driven and should occur in an evolutionary manner.
- Initiatives to address and resolve issues attendant with longer-term use of GNSS should promptly begin.

GNSS is a here and now capability that will provide major operational benefits to all users of the air transportation system. The Task Force strongly recommends implementation of an early initial operational capability and follow-on efforts to quickly resolve longer-term institutional and equipment development issues.

BACKGROUND

During the latter portion of 1991, the International Civil Aviation Organization (ICAO) Tenth Air Navigation Conference resulted in international agreement supporting the adoption of the Future Air Navigation System/Global Navigation Satellite System as a key element of the future Air Traffic Management (ATM) system. Soon thereafter, Federal Aviation Administration (FAA) Administrator James B. Busey asked RTCA to develop community consensus regarding implementation of GNSS for civil aviation use in the United States and to provide FAA with appropriate recommendations for achieving that objective.

In response to the FAA Administrator's request, RTCA formed a Task Force (TF-1), chaired by Mr. James A. Abrahamson, Executive Vice President and President, Transportation Sector of Hughes Aircraft Company, to address how and when an early GNSS operational capability could be implemented.

Five Task Force Working Groups were formed to address GNSS transition and implementation issues:

Working Group One: Applications and Required Procedures

Working Group Two: Technical Requirements and Compromises

Working Group Three: Transition Issues

Working Group Four: Institutional Issues

Working Group Five: Future Directions of GNSS Technology.

Over 200 interested aviation community volunteers, representing essentially the full cross-section of the community, participated in the Task Force effort. The group was impressed with FAA's commitment to achieving early-on a GNSS operational capability.

BASIC SYSTEM DESCRIPTION

A basic understanding of satellite-based navigation is fundamental to any discussion of Task Force deliberations and recommendations.

Satellite navigation uses a constellation of many satellites orbiting the earth to instantaneously and very accurately determine the position of users on or above the earth. The position of each satellite is known with great precision. By using satellite-transmitted radio signals to establish the distance of a user from each of several satellites, the exact position of the user can be calculated with a horizontal position error of 100 meters (approximately 300 feet) or less. The GNSS can also provide universal time with an accuracy of better than one-millionth of a second.

The GNSS can provide users, on a worldwide basis, with instantaneous knowledge of their position to an accuracy that is far better than that provided by traditional earth-based navigation equipment during essentially every portion of a flight.

The initial GNSS will consist of the 21 United States-developed Global Positioning System (GPS) satellites plus three operational spares. The Russian Global Orbiting Navigation Satellite System (GLONASS) and possibly other satellites will likely become part of GNSS at a later date.

Initially, GNSS-equipped users will have the capability to conduct en route and terminal area navigation operations using existing procedures. GNSS-based operations will also support non-precision approaches to a decision height of approximately 200 feet above the ground. Barometric altimeter data will be used as a confirming source of aircraft altitude information. With augmentation provided by ground-based Differential GNSS equipment, precision approaches equivalent to ILS Category I and potentially airport surface operations will soon be possible. Augmentation to improve the integrity of the GNSS information will be necessary until the number of satellites in the initial GNSS constellation is increased.

In the longer term, GNSS may be able to support precision approaches to lower-decision heights/minimum-decent altitudes and may also provide an alternative method for performing other important aviation-related functions.

OPERATIONAL APPLICATIONS AND BENEFITS

The goals of the aviation industry with respect to GNSS are twofold:

- to immediately derive all possible advantage from GNSS
- to replace existing navigation systems with GNSS wherever GNSS performance is superior and cost-effective or can enable applications that are not feasible today using other sensors.

Although the GNSS constellation is not yet complete, many useful applications and benefits are available today. Existing navigation systems, combined with GNSS as multi-sensor systems, can take advantage of GNSS accuracy. The result would be a major improvement in precise knowledge of aircraft position at any instant in time, thereby improving the capacity, efficiency and safety of the air transportation system.

The GNSS-based initial operational capability should provide, as a minimum, en route, oceanic, terminal area and non-precision approach navigation service. These operations are expected to satisfy more that 90 percent of general aviation's needs for navigation and landing guidance, and many needs of all aviation users.

The high accuracy and timeliness of GNSS position-fixing and navigation information makes possible a fundamental change in the way that operating minima are established. With very high accuracy position-fixing data available to users and air traffic managers, a new approach to landing categories may become appropriate. Designations such as Instrument Landing System (ILS) Performance Category I, II or III may no longer be applicable, and minima may be more appropriately established based on performance of on-board navigation equipment.

GNSS-based Automatic Dependent Surveillance (GNSS/ADS) should become an important source of surveillance information, initially in the less-dense traffic locations where secondary surveillance data is not available, e.g., over the oceans or in other areas where radar surveillance is difficult to justify. GNSS/ADS may eventually complement or replace secondary surveillance radar even in terminal area applications. GNSS/ADS may be used for operational control by the airlines and other aircraft operators. Some such applications are currently in operational evaluation.

GNSS also provides the potential to replace existing navigation systems with one system capable of worldwide, all-weather navigation. Major operational benefits expected to accrue from use of GNSS include reduced flight time, more efficient flight paths, and reduced delays — all made possible by procedures that flow from more accurate area navigation information and improved surveillance.

Users benefitting from GNSS-based operations range from the general aviation community to major air carriers. All will enjoy an unprecedented level of operational flexibility by having available at minimal cost, instrument approaches to many additional runways.

In the U.S., there are over 5,700 runways long enough to accommodate transport aircraft, yet there are fewer than 1,300 instrument landing facilities. GNSS-based approaches could provide access to both ends of these runways during Instrument Meteorological Conditions (IMC).

Augmented GNSS accuracy of five meters or better should be achievable and could support ground operations. Using GNSS information to guide aircraft taxiing on the ground or airport surface vehicles will significantly enhance situational awareness of all airport surface operations and will improve airport surface navigation thereby helping to prevent runway incursions.

TRANSITION TO GNSS

Transition from the current ground-based radio navigation system to a GNSS-based system should begin in 1993, evolve in accordance with user needs and proceed as rapidly as the FAA and users can demonstrate required system performance characteristics.

Figure 1 summarizes both the dates by which users desire a specific GNSS capability and the dates by which technology can support an initial operational capability. **The development of procedures — not technology — will determine when a GNSS initial operational capability is achieved and the pace at which the initial operational capability can be expanded.**

To encourage near-term GNSS equipage of the nation's aircraft, the FAA should adopt a policy of granting GNSS-derived benefits to GNSS-equipped aircraft. This policy will create an aviation transition environment that can be represented by a transition graph similar to that shown in Figure 2. The actual slope of the various sections of the graph will be determined by a multitude of considerations attendant with moving from point to point of the figure. However, the greatest influence of these transition factors will be determined by the FAA's willingness to grant immediate operational benefits for each incremental investment in GNSS capability and functionality.

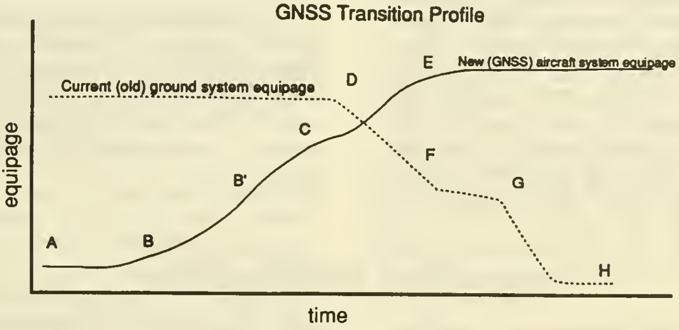
FIGURE 1:

Overview of User Needs in Context of Available Technology

CAPABILITY	USERS	TECHNOLOGY
GNSS Supplemental Means and Multi-Sensor Navigation	Now	Now
GNSS-Based ADS (in low density applications)	1993	1993
GNSS-Based Airport Navigation and Surveillance	1993	1993
Special Category I GNSS-Based Approaches (200-foot altitude and 0.5 mile visibility)	1993	1993
Instrument Approach DH <200 feet altitude	1994	1995
Distance-Based Separation Standards	1994	1994
GNSS Sole Means (Including GNSS Integrity Channel)	1995	1995
GLONASS Constellation Completed	1995	1995
Obstacle Clearance Criteria	1995	1995
GNSS-Based Autoland and Takeoff (300 RVR) Using Carrier Phase Differential GPS (Accuracy <1 meter)	1997	1997

NOTE: *The dates shown are for an initial operational capability with the first few GNSS configured aircraft flying in specific airspace and/or landing at specific locations.*

FIGURE 2:



Transition to GNSS Equipage

A	Present environment (some GNSS equipage due to perceived utility of technology)
B	Start of full scale transition to GNSS (with FAA and industry-wide backing)
B'	Point at which individual operators, at their own discretion, begin removal of current system avionics on a substitution basis. The sooner this event is sanctioned the quicker transition will be achieved.
C	Reduction of voluntary GNSS equipage. The point at which announcement of date (D) at which current system ground support services will begin to be decommissioned.
D	Start of decommissioning current system ground facilities.
E	Virtually 100% fleet equipage (U.S.).
F	ICAO announcement for final protection date (G) of existing system ground based navigation systems for international routes and airports.
G	End ICAO protection period for existing systems.
H	Continued operation of current system ground support for special (exception cases) situations and sites.

Emphasis on early transition to GNSS requires the FAA and the aviation community to place high priority on taking advantage of existing technologies, institutional resources, and capital investments. Available services should be used with as little modification as possible, to support the initial GNSS applications. In time, optimum GNSS support services and FAA and industry infrastructure can be created, evolved and sustained. The FAA should take responsibility for encouraging adoption of this approach both within the U.S. and throughout the world aviation community.

Withdrawal of current navigation aids may be undertaken in an incremental manner proportionate to the usage levels of the specific service. Retirement of current ground-based navigation aids should be implemented as soon as practical.

INSTITUTIONAL CONSIDERATIONS

The initial implementation of GNSS in U.S.-controlled airspace poses no institutional obstacles. However, the evolution of GNSS into a fully capable and internationally acceptable service embraces a set of institutional concerns that must be resolved in the near term to allow GNSS to develop to its full potential.

The U.S. Department of Defense (DoD) has agreed to provide a specific level of GPS service for use by the civil community and it will be held accountable for the provision of the service. The terms and conditions of this commitment are provided in intragovernmental Memoranda of Agreement (MOAs). If these intragovernmental agreements are legally insufficient to meet certification standards contained in Federal Aviation Regulation Part 25 (FAR Part 25) and operating rules contained in Federal Aviation Regulation Part 121 (FAR Part 121), the U.S. Department of Transportation (DOT) should take action to codify the terms of such agreements regarding GPS civil services.

Using the Administrative Procedures Act, the DOT should allow the civil community to officially comment on any proposed changes in the provision of the Global Positioning System Standard Positioning Service. DOT, jointly with DoD, should apprise Congress that GPS services are not only of national military importance, but that they are taking on a critical significance to the civil aviation community as well.

The DoD should continue to program, and the Congress should appropriate, sufficient funds to assure continuity of GPS services, as defined in the Federal Radionavigation Plan (FRP), for the foreseeable future.

Acquisition of ground-based GNSS augmentation equipment, e.g., differential GNSS stations, is an important element in achieving the best possible GNSS initial operational capability. The use of the traditional U.S. federal procurement process does not appear to be compatible with achieving the earliest GNSS initial operational capability. Alternative acquisition procedures making use of lease arrangements, private special purpose systems, government/industry shared partnerships and other forms of cost sharing should be embraced and promoted by the FAA.

Looking beyond an initial operational capability, GNSS can meet aviation navigation and surveillance needs, on a full-time, worldwide basis. GNSS services must be provided in a way that is internationally acceptable; that can integrate the various space, air, and ground components into a cohesive system that is user-transparent; that can achieve an equitable mechanism for recovering costs; and that can be held accountable for the required level of service.

The Task Force examined a number of institutional possibilities for providing long-term GNSS institutional arrangements: a regional alternative, a consortium alternative and a national alternative. For each alternative, issues of ownership, operation and control of the future GNSS components such as the space elements, their associated ground control stations and the GNSS augmentations were examined. An informed final decision and recommendation regarding the "best" far-term institutional arrangement for providing the GNSS system cannot be made until the end-state requirements are further developed and the long-term availability and viability of certain systems are known.

Worldwide coordination of GNSS planning will rest with ICAO. Insights obtained by the FAA and others during early implementation of GNSS will provide information and experience to assist ICAO.

Appropriate organizations should begin now to resolve these longer-term considerations.

TECHNOLOGY CONSIDERATIONS

A fundamental conclusion reached by the Task Force is that existing technology can satisfy the requirements associated with most operational applications thus far identified.

GNSS differs from traditional navigation systems — not only with respect to the accuracy of position and timing information and to the worldwide coverage of the system — but also with respect to the interrelationship of system accuracy, system integrity and the availability of GNSS signals. A comprehensive discussion of accuracy, integrity and availability and their complex interactions is presented in Appendix A of the Task Force Report.

In implementing GNSS, all receivers should incorporate Receiver Autonomous Integrity Monitoring (RAIM) augmented by altimetry aiding as proposed in the draft FAA Technical Standard Order

(TSO C-129). The resulting ability to determine system integrity is sufficient for all en route and terminal navigation plus most non-precision landing approaches when sufficient satellites with good geometry are in view.

Special Category I GNSS precision landing approaches should be implemented in 1993. This will require Differential GNSS service in selected areas. The existing terrestrial data link system should initially be used to satisfy the technical requirements of the application.

GNSS/ADS should be implemented to increase the position and time accuracy of the surveillance messages. Oceanic use of GNSS/ADS can be supported in 1993.

GNSS/ADS could also meet operational requirements for surveillance in Terminal Control Areas (TCA) and on the surface of airports. In the longer term, these applications will require a more robust data link with higher capacity. Additional attention must be focused on defining and then satisfying these data link requirements.

RTCA should extend standard ADS formats, as appropriate, to support aircraft and ground vehicle applications, and the FAA should complete additional GNSS-based airport surface and terminal area surveillance trials to validate ADS position update rate and data link requirements. Results of these efforts should then be considered as part of the development of the ICAO "new" data link and should be included as part of the industry migration plan to implement the Aeronautical Telecommunication Network (ATN).

A Carrier Phase Differential GPS (CPDGPS) system should also be developed to support aircraft positioning requirements attendant with the most demanding precision landing approaches.

In related areas, the FAA should, as a matter of urgency, immediately take all necessary steps to protect the internationally allocated GNSS radio spectrum from interference and implement use of the ICAO-adopted World Geodetic System 1984 (WGS-84) coordinate system. The FAA should also initiate within ICAO the adoption of Universal Time Coordinates (UTC) as distributed by GNSS as the prime standard for time on a global basis.

FUTURE GNSS IMPROVEMENTS

Notwithstanding the major capabilities made possible by the GNSS initial operational capability, GNSS can be further improved with added development.

The FAA should prepare plans to design, develop and demonstrate advanced systems and technologies that will add to the value and applications of GNSS in the 21st century. Special efforts should be made to ensure adequate research and development (R&D) funding and manpower are provided to execute these plans. As a minimum, plans should include initiatives to explore the use of GNSS-derived aircraft position information in achieving an autonomous collision avoidance capability, in providing greater warning of impending windshear/microburst hazards and in exploring the possibility of a GNSS-based automatic landing capability. Complementary efforts should also be devoted to exploring the power of velocity information and the development of improved antenna and receiver technology.

TASK FORCE PRIMARY RECOMMENDATIONS

The Task Force concluded approximately nine months of deliberations by identifying many recommended actions. Primary recommendations were summarized as follows:

Initial System Configuration and Control

- The FAA should base GNSS initial operational implementation on the use of the U.S. Global Positioning System national resource and appropriate augmentations. The early system configuration should be expanded to accommodate the Russian GLONASS and other satellites and augmentations as they become available.

  Institutional arrangements intended to protect the interest of civil users similar to those recommended in the report, must be required for other satellite systems prior to their inclusion into GNSS.

- The FAA should take an active role in planning and supporting civil uses of the Global Positioning System and assure the needs of civil aviation are met during the operation of the system.

Planning and Standards

- The FAA should use the existing infrastructure to accelerate initial GNSS implementation. Currently available services should be used with as little modification as possible.

- The FAA, in conjunction with other civil aviation authorities and ICAO, should provide during 1994 a coordinated plan for implementing GNSS on an international basis. This action is required to assure the development of interoperable GNSS procedures, map standards and equipment worldwide.

- RTCA, through which government and industry representatives can prepare consensus recommendations, should make available during 1993 initial standards that will be used to certify GNSS equipment for operational use.

Procedures

- The FAA and users should work as a true partnership as they have often done in the past, to expedite the development of safe and beneficial procedures.

- The FAA should develop flight standards criteria and basic air traffic procedures during 1993 to support initial operational implementation by some aircraft and some aircraft operators at a limited number of airports.

- The FAA needs to reach agreement with the DoD, and possibly other government and/or private sector organizations, regarding GNSS signal parameters and availability upon which the certification and air traffic procedures will be based.

- The FAA needs to establish conditions and procedures for Instrument Flight Rules (IFR) use of GNSS receivers not permanently installed in aircraft.

Acquisition

- The FAA and the aviation industry should form an early partnership to obtain, by 1994, the capacity, efficiency and safety benefits attendant with achieving early operational implementation of GNSS. In this arrangement,

  — The FAA needs to rapidly make available needed policies and procedures.

  — Industry should take primary responsibility for providing early GNSS ground-based augmentation equipment, e.g., differential GNSS stations, built to FAA certification standards, which are needed to provide landing guidance under the more demanding instrument meteorological conditions and for airport surface operations.

- GPS is quickly becoming a vital component of the national infrastructure. The DoD and DOT must jointly apprise the Congress of the importance of the GPS service and work with Congress to assure adequate and consistent funding continues to be made available.

Longer Term GNSS Operation

- The FAA, in conjunction with other civil aviation authorities, ICAO and industry, should do the planning in 1993 to more fully capitalize on the positioning and timing capability inherent in GNSS.

- Beginning in 1994, the FAA should sponsor or support the development of concepts, equipment or techniques to achieve improved capacity, efficiency and safety of civil aviation operations using GNSS beyond the capability embodied in the early operational implementation.

Challenges

The new technologies of satellite navigation, satellite communication, and the extraordinary advances in communication, computer and data processing technologies challenge the aviation industry and administrations around the world. If the new opportunities are to be grasped in a timely way, dramatic changes in our institutions and the way they view and perform their jobs will be needed.

GNSS offers a remarkable opportunity to create profound changes in the manner in which approach and landing categories and obstacle clearance standards are established. The Task Force urges the FAA to exploit GNSS by establishing capability-related minima through use of the Required Navigation Performance (RNP) concept.

While the issue of achieving effective digital communications was not fully addressed by this Task Force, the need to make early decisions on digital communications is clear. GNSS data applications are only one part of the larger need for agreements and standards for digital communications. While several data links may be required and justified, a framework is needed to assure that the plethora of applications can be served without unnecessary duplication. The Task Force urges early and intensive effort to fully resolve this critical issue in a timely manner.

The RTCA Task Force Report on Global Navigation Satellite System (GNSS) Transition and Implementation Strategy provides a more comprehensive treatment of all GNSS-issues and considerations. To obtain copies of the full report, please contact RTCA.

BOSTON PUBLIC LIBRARY
3 9999 05983 378 8

ISBN 0-16-041774-0
90000
9 780160 417740